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Automated Vehicle Anti-Theft Security System

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Table of Contents

1.0 Executive Summary

For our project, we plan on creating a solar powered, fully automated car anti-theft security system. The system is capable of sending notifications and record video footage reliably in order to keep the user's car secured. Having security footage of any incident will make car owners not only safer, but will help make events after an incident much quicker and easier to handle. By having indisputable video evidence, we can eliminate the he said/she said situation during a car accident as well.

We plan on making our project very economical, allowing for anybody to buy. This way it can be cheaper to create and cheaper for the potential consumer. We want our project to consist not only of an economical design, but also a very user friendly design. This includes making post installation maintenance minimal, we all know cars already need enough maintenance work by themselves. But we also want to make our project device easy to install and use on a daily basis. Making the device phone compatible via text and application will help make the device very simple and quick to use.

A solar powered charging system will be used to power our device and store excess energy. This way we can use the excess energy when there is not enough sunlight out to make the camera's fully functional and maintain reliability at night time or during a storm. Cameras do not consume much power, so using a large battery will mean we can have a high powering time for the cameras to all work continuously for several hours without any sunlight.

The device shall be nearly as wide and long as the rooftop of whichever type of car model we decide to use for the final presentation. It should also be locked down in position and hard to remove so thieves cannot simply try and take it off. It should be relatively lightweight and relatively aerodynamic so it does not produce a lot of drag when the car is moving at high speeds. The device will also be water resistant so that the device can be fully functional when wet.

To make the user's car as secure as possible, we plan on putting motion sensing technology into our design that can detect movement even when the car is completely off without affecting the car's battery. Once motion is detected a camera will turn on and continue recording and save video footage until motion has stopped. The car owner will also be notified through phone by a generic message making them aware of the incident at the same time it has happened.

Very few current car security systems implement these technologies, we are not aware of any that currently send real time alerts to the car owner when motion has been detected. Other car security systems do not yet offer solar powered cameras and do not have any of the features that this new device is offering. There are very few full view car security systems on the market and those very few are not connected to the top of the car and do not offer phone friendly service. Another main problem with these other security systems is that they are not centralized and require much more effort to install and replace [1].

2.0 Project Description

2.1 Project Motivation

The main motivation behind this project is simple, we wanted to secure cars without the hassle of installing highly integrated security systems and without very expensive services. Our design makes it very easy to install and get working immediately. There will be no loose wires that will have to be secured around the entire frame of the car in order to operate. There are currently car security systems available on the market, but for the most part they do not offer the compact design and independent charging like our system.

We all know there is always the potential for intruders to break into your car and steal valuables. Obviously that is why car locks are in place, and now some security systems sound car alarms which can distract the intruder and alert others nearby when an intruder breaks into your car. But the intruder still has the ability to flee the scene and never get caught on video. Our system helps detect and record video evidence while sending alerts to the car owner when someone tries to break into a car. This way, intruders can be reported to law enforcement to better identify them and have them prosecuted. The evidence collected by the cameras can also be sent real time to the owner of the car which gives immediate response and the owner can decide on further action to take.

Another major concern that is addressed is during cases of insurance fraud. Cars drivers are much more prone to this because it is very easy for scammers to file a claim against you. There are plenty of videos showing scammers running in front of cars or even backing up their car into a victim's car and then blaming the victim for damages and personal injuries. This can result in serious consequences to someone's financial status and driving record. However, with the video evidence, drivers can prove that they're not at fault and protect their record. Video evidence is one of the only forms of indisputable evidence that can be used and it is very easy to get with our security system. You have the ability to protect your life from intruders trying to take your money and property.

In the end, it is impossible to stop all thieves/scammers from hurting you or your car, but it is possible to detect, report and have video evidence to protect you and your property with our security system.

2.2 Objectives and Goals

The main objective of our project to provide a packaged car security system able to detect possible break-ins and notify owner's immediately. We are to provide a full surveillance of the vehicle, allowing for no blind spots. We also want the system to last as long as possible without running out of power. In order to accomplish this, we are going to implement solar powered energy to charge the battery whenever the car is exposed to sunlight. We are also going to have the system go idle once the user is near the car, or driving, to save power. The system will be able to recognize movement in order to start recording and not having the video

cameras record everything. The owner gets notified once the car is touched or a door is forcefully tried to open. Our main goals are listed below:

- Full coverage of vehicle
- Motion detection to start recording
- Solar Powered
- Power saving
- Notifies owner when security breach
- Sends audio alert to ward criminal

By accomplishing all of the above goals, we hope to have a security system that has its users feeling safe and unworried for their car. We hope to also have an easy-to-use, clean app that makes it simple for users to know when there is an alert and see what is happening to their car. We will have all video files saved and sent to the user if needed, and all other video files to be overwritten. This saves space on the hard drive and deletes unwanted, useless video. We hope that by having evidence of the crime on film, owner's will be able to more easily identify and prosecute the offenders.

2.3 Requirements Specifications

- **The device will fit securely on top of vehicle**
  - o Device is no taller than 1.5m
  - o No larger than roof of car: 1.5m x 1.5m
- **4 independent security cameras**
  - o Four cameras will be placed on the top of the car
    - i. Two cameras will be placed on each side of the car, each having a wide viewing angle
    - ii. One camera will be facing towards the back of the car
    - iii. One will face forwards, being activated to work as a dash cam when driving.
- **Motion detection to detect any potential threats**
  - o Detects movement from up to 2 meters using PIR
- **Capability to send alerts wirelessly to user's phone**
  - o Using Wi-Fi/Bluetooth for wireless communication
  - o Able to be notified in timely matter; no more than 30 secs
  - o User also able to send audio alert back to device
- **Solar Powered Battery**
  - o Solar Panels charge battery during day
- Audio amplifier speaker

- o 5-25 cm speaker allows user's audio alert to be heard by intruder
- o Warns intruder potentially stopping the crime
- Main Storage Device
  - o Able to hold at least 10-15 min. of footage
  - o Begins overwriting data when full
- Basic Processor
  - o Will delete old digital data when space is full
  - o Will cut charging to the batteries once they have reached capacity
  - o Send automated reports and start recording when receiving threshold inputs from the motion detector
- Three layers of the device:
  - o The bottom layer
    - ▪ Baseboard made of durable plastic
    - ▪ Securely attached to the top of the vehicle
  - o The middle layer will consist of the hardware
    - ▪ Including a battery, a digital data storage platform, cameras, and a PCB board
    - ▪ Covered in weather resistant material
  - o The top layer
    - ▪ Consists of a single solar panel
    - ▪ Each connected directly to the battery in the middle layer
  - o Sealant will be used to keep everything waterproof
- Phone Application
  - o Simple, Clean, and Easy-to-use
  - o Displays alerts and allows user to contact appropriate authorities or alert back

3.0 Research

3.1 Previous Works

To better understand our projects needs and to develop a more efficient device we can explore past works, whether largely successful or not. Examining the pitfalls can be just as, if not more, beneficial than solely viewing the successes of a project with similar goals. In researching other past works, an emphasis was placed on those that involved: Solar power use, camera modules, video feeds, movement sensors, and wireless communication.

eMpower – Solar Powered mobile device charger with remote control

This project's goal was to create a solar powered platform capable of charging mobile devices. This project would be used commercially by requiring payment from a client before allowing power to flow and charge their mobile device. The primary means of communication and administrative control would flow through a GSM connection and SMS text messages. An administrative user would be able to send a command via a SMS text message that would turn on and off charging ports, update time and status, and receive performance metrics. Due to the nature of the project, the continuous fees received from clients would be able to fund the overhead cost of maintaining service via a GSM chip and wireless network, as well as provide a means of profit.

For our vehicle security system, the required monthly payment that accompanies the access to a GSM network conflicts with the ideal pricing paradigm in mind, e.g. one time purchase of a centralized device that can operated without further overhead costs. Many potential customers would be deterred by the addition of a monthly fee. As well, from the perspective of the customer, a continuous service fee would be expected to come with an additional service such as technical support, software updates, and expansive functionality. By adding an additional support & production phase to the life cycle of this product, this would increase the costs associated exponentially. Continuing the development of our project, we will need to keep in the mind the pros and cons of added functionality versus the cost in implementation. [2]

ECO-SEC – An Economical Solution to Home Security

To better understand the needs of the vehicle security project, it's helpful to investigate another project that has utilized many processes and capabilities that we anticipate employing ourselves. This project's goal, as expressed by its title, is to create a home security system. The ECO-SEC's objectives align similarly to ours in several ways, including camera surveillance, video data storage, motion detection, and solar charging. As well, a similar observation of the effects and continuous cost of utilizing a GSM wireless connection was considered in this project. As a means of interfacing this project utilized an LCD touch screen display. This differs from our approach of developing a mobile phone application. The difference we note is a reduced cost of the project as a whole, with less hardware requirements in the device itself. However, this change now introduces a new

hardware requirement that is localized to the user itself, meaning the mobile phone or tablet device.

In the past several years however, it has been shown that the use of mobile devices is almost ubiquitous, especially with respect to the targeted clientele and consumers of our project. Thus, a mobile application would be easier to use, more localized to the user, and reduce the hardware cost of the project. Another helpful aspect of the ECO-SEC which helped to guide the research and direction we took with our vehicle security system is the use of a web server. They were able to utilize an embedded web server chip via Ethernet connection to provide the I/O interfacing needed for alerts and communication to the user. With respect to our project the exact implementation would not be directly translatable.

This is primarily due to the more mobile aspect of our device, as it would be located atop of the user's vehicle with clearly no access to an Ethernet connection. However, it does bring upon the idea of a mobile embedded web server which could help to accomplish our projects task of live video footage of the security cameras as well as alerts. Finally, other useful portions of this project are the study of power generation, distribution, and consumption of the system. This project used a charge controller that was able to regulate varying incoming voltage from the solar panel to an acceptable level for the lithium ion battery to charge effectively. The charge controller could be viewed loosely as a 'catch-all' that would allow more freedom in the present DC – AC conversions efficiently and stop charging when max capacity was reached. [3]

Motorcycle Tracking Security System

This project was also very effective in supplying useful experience with respect to our vehicle security system. The device was integrated into the motorcycle helmet itself and provides capabilities to communicate to a mobile device via a Bluetooth module. The project used Bluetooth to sync with and interface directly with the device, ultimately playing music or making phone calls via the motorcycle helmet. GSM communication design was also explored as a technique for user alerts via SMS text messages. One key investigation this project made was into the different types of microcontrollers that could be utilized in processing and logistics that were required by the system. They went with an Arduino board noting its third-party support available online via forums and videos.

This has helped give us insight into what sort of options are available to take advantage of, with a similar competitor being the raspberry pi. The third-party support and widespread use of both of these microcontrollers are large factors with respect to which one to finally choose to use. Not only previous works and examples of use, but compatible modules for Bluetooth, wi-fi, and power as well as processing speeds and available memory need to be considered. The requirements of the motorcycle security system have made it a good fit for the Arduino for its low cost and power consumption.

A raspberry pi on the other hand would be seen as more powerful with its ability to run a standalone operating system although seemingly much more complex. Introducing a more powerful component like a raspberry pi initially seems to be a

purely beneficial addition, however us as engineers must also realizes the possible added difficulties of maintaining said component and utilizing it effectively. Like many other decisions that must be made in the completion of this project and its goals, the tradeoffs and pros / cons must be considered. [4]

3.2 Hardware Components

3.2.1 Power

3.2.1.1 Solar Panels

How Solar Panels Work and Background

Solar panels will be used for our design and we will provide enough electrical energy needed to keep our design running without having major power droughts. They are a very convenient source for low electrical power consuming applications and are readily available to buy. Solar panels are also commonly known to be very environmentally friendly and fairly easy to install. They will be placed on the top of the design to obtain as much sun light as possible and then convert this energy into DC electrical energy. In this section we will give some background on solar panels and how they work. For this explanation of how solar panels, we will give the overall idea of how generic solar panels work.

Solar panels are made up of several small units called photovoltaic cells. These cells use the concept of the photoelectric effect which is the idea that sunlight can be used to produce electricity. A short summary of the basic idea of how these cells work will be given followed by analysis on the different types of solar panels comparing each to determine which is most applicable to our project.

Photovoltaic cells work by using an electric field to push electrons so they can become free flowing and hence produce electricity. Silicon junctions are typically used and are created where one piece of material is positively doped and the other part of the junction is negatively doped [5]. With this difference in net charge between the two oppositely doped materials, a small electric field is created. Sometimes there is a small neutral material placed between the two oppositely charged materials. When the two oppositely charged materials are in contact, a depletion region is created which prevents electrons from leaving the negatively charged material (N-type material).

But with this electric field and some external energy, electrons can flow freely and move out of the depletion region and they have enough energy to move away from their parenting atom creating current. From this, it is clear that an external force is needed to push the electrons away from the parenting atoms and into the positively charged material (p-type material). Photons pass through the front of the solar panels and excite the electrons on the negatively charged material in these photovoltaic cells to create current. So it is important to keep the solar panel clean and free of any objects so as many photons hit the solar panel as possible. Different types of photovoltaic cells are made with different types of materials which ultimately create different properties for the solar panels. This will be

explained more in the next section where we discuss the different types of solar panels [5].

Now we will look at how solar panels are connected and determine if we require enough power to use multiple solar panels or just one. The next level to solar panels involves connecting all the small photovoltaic cells together to get a larger amount energy that is large enough to be used for most applications from charging batteries to powering homes. Several of these photovoltaic cells are connected together and formed into a photovoltaic module [6]. They can be connected in series or in parallel to increase voltage or current. At this stage, the photovoltaic cells are connected together and then covered to become waterproof. They are also covered in a laminate material on the front side so that sunlight can easily pass through the water protective laminate material and hit the photovoltaic cells. Once this is done, the modules can be connected together to form the solar panels that are readily available for commercial use. After looking at various different models, it was found that solar panels typically are expensive up front but have almost no operating cost. Even though they are expensive, due to the little maintenance required for solar panels, we decided solar powering would be the best choice for our design to be independent of getting supplied power from the car.

The main problem today with solar panels is the fact that they are very inefficient so they require a lot of space to produce necessary amounts of power. There is also the fact that solar panels only produce electricity in sunlight, so at night or during cloudy weather, there will be virtually no energy produced. That is why for our design we will be storing all excess energy in batteries that will power the design even when there is no solar energy readily available. That way our design can be operational and work regardless of weather conditions.

Types of solar panels and which is best

For our design, we will find the most economical type of solar panel that can fit on top of the vehicle that can also produce enough electrical power to have excess power stored. The most popular types of solar panels that are commonly used today are: monocrystalline silicone, polycrystalline silicon and Thin-Film [7]. However, there are also different types of commercially available solar panels that differ on more than just the type of material the photovoltaic cells are made of. For example, there are some solar panels that are flexible and can fit comfortably around any contour. This will be taken into consideration because our application involves using the top of a car and most cars have a curved contour. We will look at how these three types of solar cells are created and then the advantages and disadvantages of each.

First we will look at the different materials that make up the photovoltaic cells for the solar panels and see how they differ. Monocrystalline silicon solar cells are made of are large cylindrical piece of silicon which is cut down to create silicon wafers [8]. Polycrystalline solar cells are similar to that of monocrystalline ones but have an efficiency of only around 14-16% [9]. The major difference however is that polycrystalline does not use entire silicon crystals to make their photovoltaic cells.

Polycrystalline solar cell creation is a recently new method that is starting to become a more popular technology in the solar cell market because they are cheaper to produce [8].

Crystal silicon is a very popular material that is used in both these designs because it is a stable material that can work well under heated conditions and last a long time. Silicon is also already used today to make many micro devices like embedded processors and many other integrated circuits. This is all important in that knowing the process that is used to create these solar panels, we will be able to better identify potential weaknesses in each type of solar panel and better understand problems when they occur during building and testing.

The next type of solar cell is Thin Film which is a new technology that is very different than the previous two types of solar cells. Thin Film solar cells are made by putting photovoltaic compounds onto a substrate which is normally made out of glass [7]. There are several different types of photovoltaic compounds that can be used like amorphous silicon or cadmium telluride. Thin Film technology is the easiest to mass produce because no silicon crystal is needed since amorphous silicon can be used. Also, the compounds can simply be layered on top of each other in an easy process without the need for cutting silicon crystals and using complex methods to create the photovoltaic cells on a silicon wafer [10]. Thin film also offers more sub types of solar panels since they can be made out of different types of photovoltaic compound materials. This also means there is plenty of room for research and future growth with these sub types of solar panels. The four main materials used today for thin film solar panels are: amorphous silicon, cadmium telluride, indium gallium deselenide and thin-film silicon. But also, this may be the best type even though it is the least efficient because it can withstand very high temperatures and still operate normally without losing the efficiency of the solar unit. However, thin film also offers a smaller efficiency rating from 6-11% [9].

Since monocrystalline cells are made of single crystals grown in the shape of a cylinder, they produce circular wafers and this circular design is then edged and trimmed to pack several of these circular wafers close together. Polycrystalline solar cells however use square shapes for each wafer so they do not waste as much space on the solar panel. Finally, thin film uses an entire sheet and therefore does not need to push several wafers close together. Each of these types of solar panels looks different and this is shown in the figure below [11]:
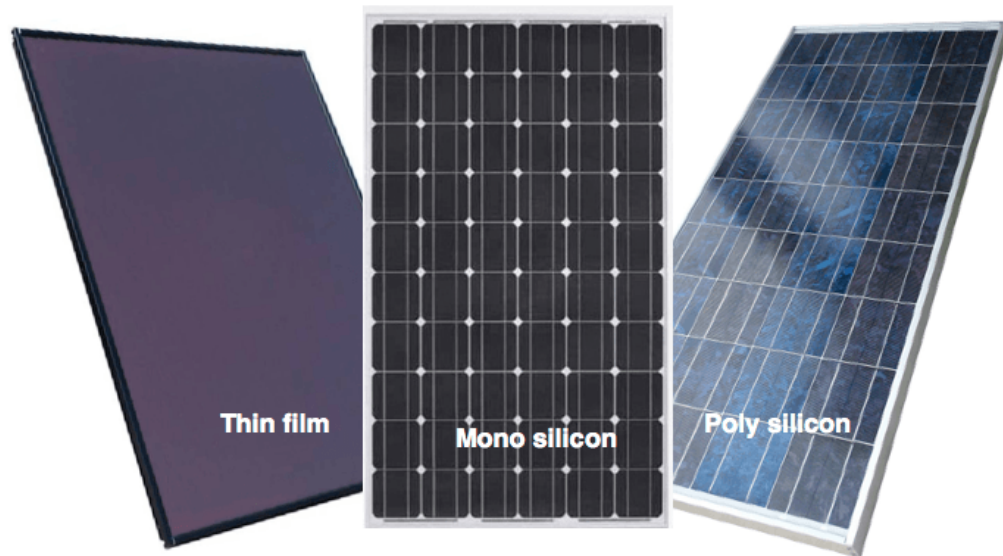
Figure 1. Different types of solar panels (Reprinted with permission from Clean Energy Reviews)

The are several advantages to using these different types, for monocrystalline, the argument can be made that these are the most efficient types of solar cells. There is also extensive research being done to find the highest achievable efficiency for monocrystalline solar cells. Here is a list of the main advantages of using Monocrystalline solar cells:

- Monocrystalline are the most efficient solar panels. They're the most efficient not only in terms of energy produced but also in the amount of space they will then need to take up. This is a crucial factor for our design because we will be limited to only be able to use the space provided on the sunroof of the vehicle we use [9].
- Monocrystalline cells also can last a relatively long life time around 25 years; which some manufacturers offer 25-year warranty on their solar panels. Meaning for our project, we will not have to worry about short lifetimes [9].

Some disadvantages of Monocrystalline cells include:

- Monocrystalline solar cells are the most expensive to produce [9]. They could be more expensive when purchasing several at once but after looking at various different prices of 100 watt panels, it was found that the cost is only about 20-30$ more for monocrystalline than polycrystalline.

  For our design, we will consider buying this type because they offer a very high efficiency rating up to 20% which may be essential to power our design using the small area provided by the vehicles sunroof. Next, as previously mentioned, polycrystalline is cheaper to produce due to the simpler process of making the silicon wafers, this is about the only major advantage over other types of solar panels that needs to be explained in this design [9]. However, some disadvantages of Polycrystalline solar cells include:

- Polycrystalline solar cells are not as efficient as monocrystalline and tend to have an efficiency anywhere from 14-16% [7]. Again, could be a major concern for our small allowable space, we will do experimenting and find out exactly what type of wattage we need for our solar panel and this will tell us if we can sacrifice space for cost or vice versa.
- Polycrystalline solar cells also have a relatively lower heat tolerance than monocrystalline solar cells but this difference is usually so minor it is negligible [8]. This will be noted and need extra attention because we live in a very hot state and gets really warm during the summer.
- Polycrystalline solar cells have a blue color to them compared to monocrystalline or thin film technology which have a color that is almost completely black. However recently, polycrystalline solar cells have taken on darker colors that almost matches monocrystalline and thin film color [12]. We want our design to look as clean as possible however this should not be a major concern.

Finally, some advantages from thin film solar cells include not entirely mentioned already:

- Can be made flexible [8]. For our design this means they should be easier to work with and will look better as the top part of our design if they can curve around the top of the car so it does not look like a flat box on top of the user's car which takes the aesthetics and potentially aero dynamic efficiency away.
- They are cheaper than monocrystalline solar panels [7]. As previously explained, cost is a constraint as long as space and power consumption.

Given all these advantages, there are some major disadvantages which make these solar panels evenly matched with the other types.

- Thin film solar cells require a lot of space because they less efficient than crystalline solar cells. Of course, this means they require more space for the same amount of output energy produced as crystalline structured solar cells [7].
- Thin film solar cells these solar cells normally don't last as long the other types of solar panels [8]. Our design needs to be shown to last a decent lifetime in order to be a huge success.
- Not as widely available in terms of what's on the market [9]. So they may be hard to find and might not be worth the effort of buying.

In all, our design will more than likely only require a small amount of solar power. Looking at various different models, it was clear that monocrystalline is the most popular and When buying small amounts of solar panels for smaller projects. It is clear too that monocrystalline as mentioned is the most efficient which is a crucial factor. We will also make sure they have a sturdy structure that is not flimsy and has points on it that can easily be secured onto our chassis.

3.2.1.2 Charge Controllers

In order to use solar panels, we need to get a charge controller and a battery bank to store all the electrical energy produced by the solar panels. There are different types of charge controllers and it depends on what type of solar panels we use and their wattage/voltage ratings. The type of charge controller can also depend on the battery bank that it is attached to. First thing to look at is how charge controllers work and why they are needed.

A charge controller is a device that regulates voltage/current to create the right conversion from the solar panels output to the batteries input and to prevent the battery bank from over charging and also prevent leakage current when the solar panels are not creating energy. Solar panels when operating create one-way direct current to the charge controller, but when they are not in use, for example at night time, they can start leaking current from the battery source they are connected to in the opposite direction of normal operation. This reverse current is typically not a serious factor, but can easily be prevented using charge controllers. Charge controllers are also used in all sorts of applications and electrical energy conversions, not just for solar energy [13] & [14].

Charge controllers second important use is to prevent overcharging of any battery bank. The charge controller can prevent overcharging by waiting until the battery is at a specific threshold voltage and when it gets to this voltage, it cuts off current to the batteries. If energy continues to be supplied to the batteries after they reach a maximum voltage, serious damage can be done to the batteries by changing the chemicals inside the battery and possibly causing it to explode thus not allowing it to work properly anymore. Depending on the type of charge controller, the current can be either immediately switch on and off, or slowly decrease the current until the batteries are fully charged [15]. The charge controller has points where the amount of energy supplied to the batteries changes, these points are called set points. These set points can be set based on a number of reasons including the temperature of the batteries they are supplying. We will have to decide if this is necessary in our design because our battery pack will be exposed to normal outside conditions which could result in the batteries getting very warm during the day time. Charge controllers can have temperature sensors built into them so we will need to look for these types of charge controllers. The set points can also change based on the type of battery used: sealed versus unsealed [13].

Charge controllers can also come with low voltage disconnect which prevent the batteries from draining too much. If the batteries drain all their power, the batteries can become permanently damaged and may not be able to store as much power as they were intended to. Normally, batteries are only supposed to lose 80% of their charge. Just like overcharging, undercharging can cause permanent damage to the batteries and so there needs to be regulation to prevent this. This can be done with low voltage disconnects which disconnect the batteries from load temporarily. More set points can be used to detect when the batteries go under a certain operating voltage. Depending on the battery pack we choose, we may need

external circuit breakers to prevent too much current from flowing than the batteries can handle. Some charge controllers have this built in [15].

Charge controllers have different modes they operate in. The first mode is a mode that is not common and is used to help protect the efficiency of the batteries. It is called the Equalization charging voltage and occurs once every 10-20 days to help desulfate the batteries; this also helps the batteries last longer. The next stage is called the boost charging voltage where the controller is simply charging the battery. Float charging voltage is the next level and is used to reduce the voltage when the battery reaches a high enough voltage to indicate it has reached charging capacity and this is usually at 13.8 volts. The last stage is called Low Voltage Reconnect/Disconnect, which are levels where the load cuts off. This last stage is used for controllers that have load terminals. Load terminals allow you to attach the DC load to the controller rather than to the battery. Each one of these levels can be user defined on the controller [16].

Types of charge controllers

There are two main types of charge controllers called: Pulse-Width Modulation and Maximum Power Point Tracking. The differences will be looked at first and then the advantages and disadvantages of each type. Like the different types of solar panels, it is not a matter of which is better in general overall, it all depends on the design they are used for.

Pulse-Width Modulation is the best type of controller in terms of maintaining a constant voltage across batteries. During charging, this type of controller allows as much current allowed by the battery as possible and as soon as the battery reaches the set point voltage the controller switches the connection between the batteries and the solar panels [17]. Pules-Width Modulation is the simpler design of the two types of controllers and normally has an efficiency from 75-80% [16].

Some advantages of Pulse-Width Modulation include [17] & [18]:

- Cheaper than maximum power point tracking controllers, which is important in terms of cost, will not need to spend extra money on MPPT if this is available for the same applications for cheaper.
- Longer life expectancy because of fewer components, this also means it is less complicated and easier to troubleshoot/put together for our project.
- Smaller size so it will be able to fit more likely in our chassis.
- Because of the cheap cost, it is better for low power applications like ours.
- Performs well in warmer weather which is one of the main concerns we may face when building and testing.

Some disadvantages of Pulse-Width Modulation include [17] & [18]:

- Not as efficient as maximum power point tracking, but again this shouldn't be a major concern for our low power consumption project.
- The solar panel power and battery bank power must be sized and rated very close to each other, this is important to know so we do not destroy the

batteries by assuming the charge controller can convert higher solar panel voltages to lower voltages.

Maximum Power Point Tracking is not directly connected to the battery, but has a DC/DC voltage converter than can convert voltage into current so that the battery is supplied lower and lower voltage so it does not overcharge [17]. These controllers are more integrated than that of Pulse-Width Modulation because they measure the maximum operating voltage and current of the panels under different conditions. They normally have an efficiency around 94-99% efficient. They are more efficient because they are able to use more power using boost current [16].

Some of the advantages of Maximum Power Point Tracking include [17] & [18]:

- Highest charging efficiency especially for higher power applications
- Much higher input voltage rating
- The solar arrays can be oversized much higher in comparison to the battery bank
- Can provide boost current in cooler temperatures and when the battery isn't charged

Some disadvantages of Maximum Power Point Tracking include [17] & [18]:

- More expensive than pulse-width modulation controllers

In order to find the right charge controller, we will look at the voltage/wattage for both: the battery pack used and the solar panels used. The first step when finding out the right rating for the charge controller is to look at the voltage of the battery bank being used, this can range anywhere from 6-48 volts. Next, look at the power rating of the solar panel, we will be using a smaller power rating solar panel anywhere from 50-200 watts. We divide the power of the solar panel by the voltage of the battery bank to the needed amperage, from this, we can choose a charge controller that will the next higher current rating than that needed to power the design.

We can also use a safety factor which is recommended to be 1.25 to find determine the best charge controller. The safety factor is multiplied by the amperage rating previously found and then the next higher value closest to this newly found safety amperage rating is used to find the right charge controller. Charge controllers can get more expensive with the higher the amperage rating so it is best to get the lowest rated charge controller that can safely charge the design [18].

In all, it is important to keep set points for the charge controller we use and make sure it has a temperature sensor and a low voltage disconnect. It is more economical to use a pulse-width modulation controller and probably more practical because our design will be relatively low power consuming; since PWM controllers are the optimal choice for applications using less than 150 watts. However, if we need as much power as can get from the solar panels because of lack of power, we may have to use a MPPT controller instead.

3.2.1.3 Types of Batteries

Now we will look at the different types of battery banks and the advantages and disadvantages of each type. This includes looking at the different property types of different batteries as well as the different voltage ratings and how they differ. We will discuss the three main types of batteries used for solar cells: Lithium-Ion, Lead-Acid and flow batteries.

Lead Acid batteries are mostly used for higher power applications where weight is not large concern. There are two categories of lead-acid batteries: flooded and sealed. They are made of the same chemicals, but flooded batteries require upright orientation and routine maintenance of the electrolyte. They also require ventilation. Because of these constraints, we probably will not use flooded batteries because our design will not be stationary and so if we used flooded batteries, electrolyte leakage could occur from car movement. Here are some advantages to look at when deciding on what type of battery for lead acid type batteries [19] & [20]:

- Have a high overcharge tolerance, meaning they will won't die as quickly as other battery types when left to charging after reaching full capacity, this is good because we may be doing a lot of testing and require the batteries to always work, we do want a battery that is tolerable so when we are testing them and we get close to maximum charge/discharge rate, they will still work.
- They are cheaper than lithium ion.
- Can discharge at high rates, this is very important for us because we need batteries with high discharge rates so they we can ensure there is enough power supplied to the Raspberry Pi modules at all times.

Some disadvantages to look at when deciding on what type of battery include [19] & [20]:

- Every 8°C above room temperature it operates at, the lifetime gets cut in half. This means that if we keep a lead acid battery at elevated temperatures, it will shorten the amount of cycles the battery will last.
- Typical batteries last for 200-300 charge-discharge cycles at high efficiency (not a lot compared to other batteries which can last up to 1500 cycles). If we want a truly operational design, we need to consider how often certain components will need to be replaced and determine if we can use substitute components that can last longer.
- Weighs a lot compared to other types of batteries, we have limited weight because we want our design to only be on top of a car and we cannot have a 50-pound battery inside or design case, this will make the car very top heavy.

The next type of battery is the lithium ion battery. Lithium is a very good material for batteries because it is lightweight and provides the largest energy density per weight. Lithium ion batteries have good load characteristics and allow for high single cell voltage allowing for very simple one cell designs. However, it is a good light weight material but it requires a protective circuit that prevents overcharging

and too much discharging. Also, these batteries can start deteriorating whether they are in use or not. The aging process can be prevented by keeping the batteries in cold conditions are 15ºC. Regardless, lithium ion batteries are the fastest growing battery and there is a huge amount of research being done on them. Some advantages of lithium ion batteries to look at when deciding on what type of battery include [19] & [20]:

- High energy density, this is a huge deal for us because we know some batteries can be 50 pounds for the potential amount of battery capacity we might need.
- Can be very small and compact, this is good, we want our design to not only be light weight but also be thin enough to fit the contour of the top of a car without sticking out more than probably 8 inches. It would look really bad if we had a system that was sticking up 2 feet above the top of a car and also reduce the aerodynamics of the car.
- Charge time from 2-4 hours, depending on the type of lead acid battery, this can be much faster charge time than lead acid, this may be important because we may only get 4-6 hours of sunlight a day and we want the batteries to be able to fully recharge each day to supply enough power when the batteries are not being charged.
- Cycle life from 500-1000, as previously mentioned, this is something that can change the shelf life of our design.
- Higher temperature resistance than lead acid batteries, which is very good because we want batteries that can work in warm weather.

Some disadvantages of lithium ion batteries to look at when deciding on what type of battery include [19] & [20]:

- Not as high of a discharge current as lead acid batteries, we will need a higher discharge current than typical use because we will have to power 4 systems at once, so we will look at the ratings
- Expensive compared to alternatives.

It is clear that there are two main types of batteries to look at when deciding which to use for this solar design. One of the main things to focus on is which type of battery will discharge faster and deliver more to the load in a short amount of time. If our system is triggered so that all the cameras are on constantly, and alerts are being sent, each component could be using a lot of power during this time, this means we need as much power as possible when the system is triggered. The graph below shows comparison between VRLA (the same as SLA) and lithium ion batteries. To better understand the graph, the VRLA line shows that over a 4-hour period, less than 80% of the capacity is discharged to the load. However, for the Lithium Ion battery, over 90% of the charge is drained to the load during this time [20]. This graph shows the different Discharge rates of SLA (VRLA) Batteries and Lithium-ion Batteries against capacity
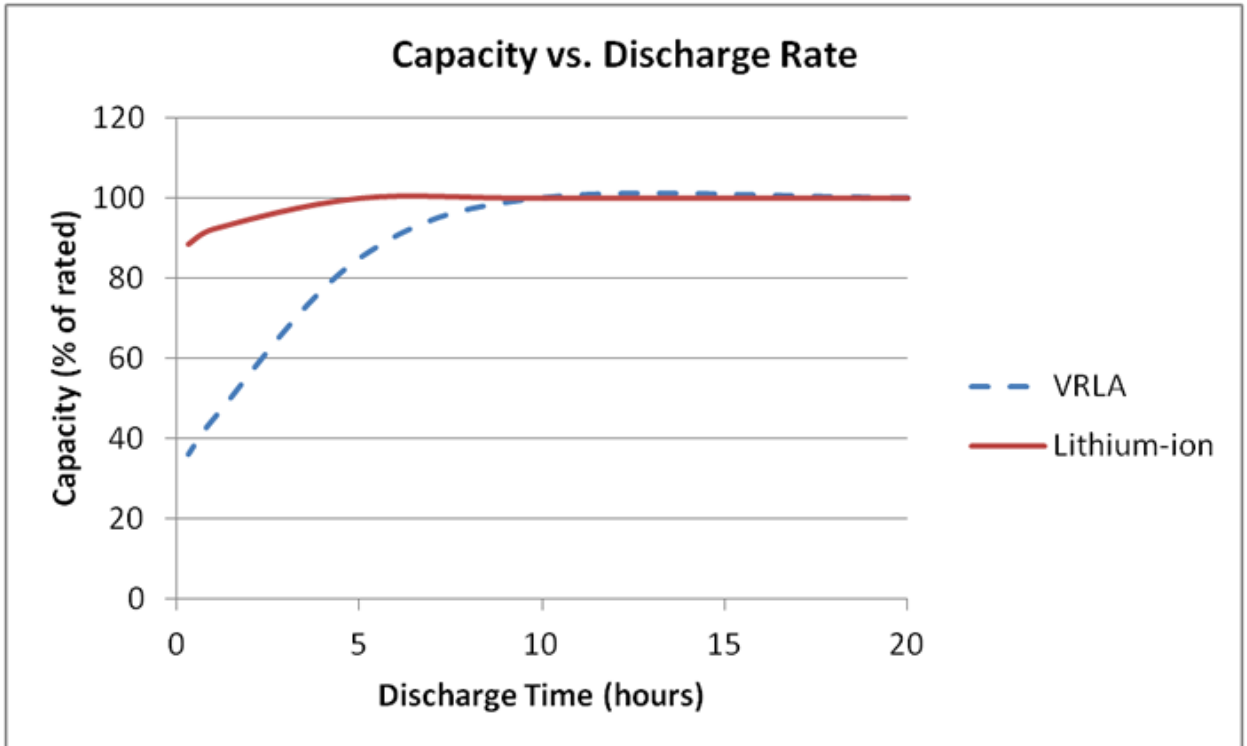
Figure 2 Graph of Capacity vs. Discharge Rate (Permission Pending) [20]

According the above graph, Lithium Ion batteries are better at passing more power to the load over shorts amount of time. When calculating how much power the components need especially when the entire system is on, we will decide whether lead acid are capable of discharging at needed rate for operation.

3.2.2 Cameras

One of the major components of our design is the use of cameras. Without cameras, our security system wouldn't work as intended. We plan on having upwards of 4 cameras in our design. Each camera will be placed in a way so that the entire car, or 360 degrees, are covered. The easiest way of accomplishing this would be by placing one camera for each side of the car. Along with viewing angle, we also have to be sure that the quality of our video is high enough that users are able to make out what they are seeing. To insure that we meet all of the specifications, we look at three major components when searching for a camera: Frame Rate, Resolution, and Focal Length.

Frame Rate

A frame rate is essentially what the name implies, the rate of which frames are being shown. A video is comprised of many still images. Each of these images can be related to a frame. The illusion of a "moving" picture is that of many still frames being displayed rapidly one after the other. The rate at which these frames are being shown is expressed in frames per second (FPS) [21]. Another way of measuring this rate, especially with digital filming, is called the "refresh rate". This

rate is measured in hertz (Hz) instead of frames per second. Even though these two rates measure the same phenomenon, they are not equal. The frames per second relates to how many frames are shown within a second. However, in order to reduce jitteriness, many times the same frame is shown two or more times consecutively before switching over to the new frame. Because of this, frames per second refers to the number of complete still images shown every second. On the other hand, the refresh rate is the total number of times any image flashes over the course of a second [21]. This means that if the same frame is shown consecutive times, the refresh rate would count each individual image while the frame rate just counts each different whole image. Different frame rates for media are regulated by the Society of Motion Picture and Television Editors [22].

Since 1927, the standard frame rate for films has been 24 fps and television has been 30 fps [22]. The human eye is capable of differentiating between 10 to 12 still images per second before it starts to blend it together and view it as motion. This means that anything that is displayed at a frame rate of 12 fps or less, your brain will pick up the images as just a bunch of stills flashing in a rapid succession. However, once you start to reach 13 fps and higher, the images start to blur together into a seamless animation [21]. Even though this motion effect starts at around 13 fps, it isn't very clean looking until around 18 fps to 26 fps. This means that having too low of a frame rate will make your video more of a slideshow. The standard for movies is at 24 fps for a good reason. At 24 fps, our brain is able to pick up the motion effect, but may pick up on the lack of frames. To compensate, there is motion blur. This effect takes place when your eyes move too quickly to process levels of detail. To replicate this effect, when switching between low frame rates, the extremely quick flash of blankness before each new frame causes our eyes to pick up a motion blur [21]. Because of this, having higher frame rates isn't always necessary and is much more cost effective not to. But having too low of a framerate will make the video come out as images. This "balance" between cost effectiveness and quality is a major factor in deciding which camera fits best. The standard for most commercially bought cameras are around 30 frames per second.

Resolution

The term resolution describes both pixel count and pixel density. Different devices use different units to measure for resolution. Digital cameras measure their resolution based on megapixels [23]. Megapixels can be defined as the measurement of how many millions of pixels the camera's sensor captures in order to produce the digital image. This means that cameras having higher megapixel counts are able to capture more information than those with lower megapixel counts. However, not all pixels in an image sensor are used to capture an image. There are many different reasons for this. Some common reasons could include some pixels being used to modify the aspect ratio of the final image or even having pixels used to measure black points. These points are used as a reference point (the point where no light reaches) and are important during exposure and processing the final image.

Most cameras that display the megapixel count are displaying what is known as the "effective" megapixel count. This is the megapixel count that is actually in use to gather the image. Instead of just how much information is gathered by the pixels, another way of thinking of a cameras resolution is how large an image can be reproduced. If a cameras resolution is too small, once the image is transferred to a new medium, it may not come out correctly. This is important to note especially when converting the file over to a digital display. This is because when looking for a camera, not only do we care about the amount of megapixels the camera itself contains, but what resolution it can produce once the video is transferred to a monitor.

The primary factor in monitor resolution is the actual number of pixels the monitor is able to display. Most displays have a "native resolution" that represents the actual number of physical light-emitting pixels on the display. This is the resolution in which images will come out optimally. Different resolutions being forced onto the monitors can cause a drop in quality for the image. Resolutions not only describe the number of pixels horizontally and vertically on a display, but are also broken into categories. For example, XGA (Extended Graphics Array) is defined as 1024 pixels horizontally by 768 pixels vertically, while SXGA (Super Extended Graphics Array) is defined as 1280 pixels horizontally by 1024 pixels vertically. Along with resolution is Bit depth. Bits are able to store two values (1 or 0), but when dealing with resolution, these bits determine the amount of tonal information is able to be stored. Most digital images are stored using either 8 or 16 bits for each of the three color channels (red, green, blue). This allows for there to be 256 to up to 65.536 tonal values for each color. Higher definition images can be stored as 32-bit images. Resolution is a major key in determining a type of camera. Having too low of a resolution can cause images to be unrecognizable. However, having too high of a resolution can bode pointless and a not cost effective. For our project, we need a resolution that is high enough to be able to identify individual people in the video. [23]

Focal Length

The focal length is not a measurement of the actual length of a lens, but instead a calculation of an optical distance from the point where light rays converge to form a sharp image of an object to the digital sensor [24]. This measurement is usually represented in millimeters and is determined when the lens is focused to infinity. The focal length is primarily useful for telling us both the angle of view and the magnification. The angle of view is important when determining how much of the scene you want captured in a single image. The magnification determines how big the different objects in your scene appear in the image. The longer the focal length is, the narrower the angle of view and the higher the magnification. On the other hand, the shorter the focal length, the wider the angle of view is and the lower the magnification is [24]. A full-frame camera has sensors that are the same size as a 35mm film frame [25].

Lenses that are longer than 50mm are considered telephoto optics because they have an angle of view that is smaller than our eyes. This causes the images to

appear more magnified than what would appear to our normal eyes. Our eyes have a natural focal length of around 50mm [25]. The lenses that have shorter focal length than 50mm are usually considered "wide-angled" lenses since they view a wider angle than that of our eyes. The angle of view is the more important of the two factors of the focal length when dealing with our project. To illustrate the angle of view, one can imagine two lines from a lens optical center to the outer opposite edges of a scene visible through the lens, the angle between these lines is considered the angle of view. The angle of view isn't limited to just horizontal. The angle can be measured in any direction, even diagonally. Lenses are also categorized into either prime or zoom. Primary lenses have a fixed focal length while zoom lenses have variable focal lengths [24]. For our project, we won't need zooming in and out, so a primary lens should do. We will also want a focal length that is at most 50mm. Having too large of a focal length will limit the amount of area the security cameras are able to pick up.
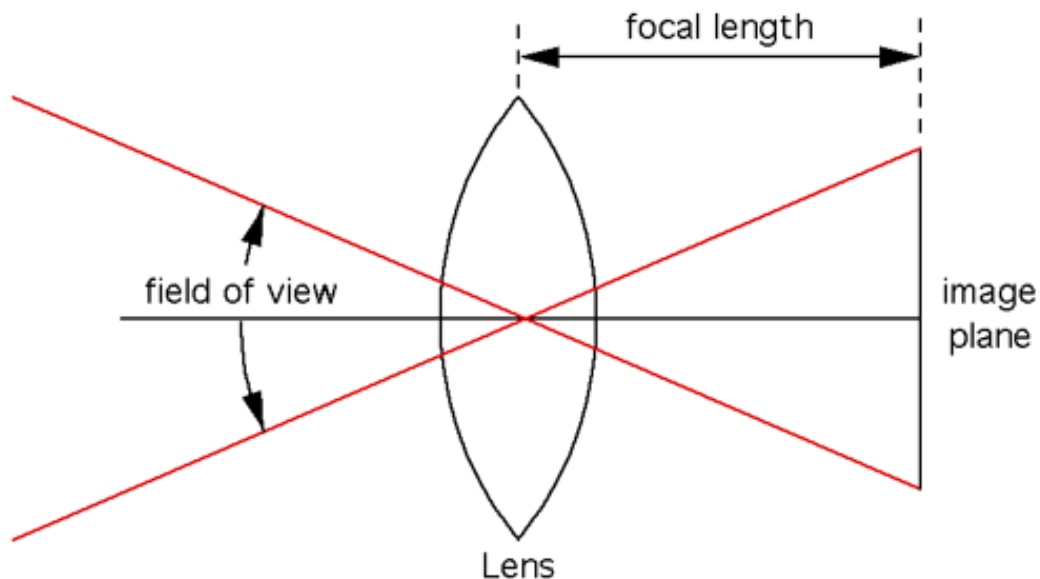
Figure 3. Focal Length (Reprinted with permission from Paul Brouke)

There are hundreds of different cameras on the market to choose from. For this project, we are looking for a camera that has several different key features. We need a high enough framerate to get a steady motion for the video. We also need a resolution high enough in order to be able to make out what is on the image. The last major feature we are looking for is the focal length to be small enough that we are able to cover all of the car. Along with these features, we are looking at other factors including cost and size.

Camera Model	Camera Module v2 [26]	ELP-USBFHD01M-L180 [27]	ELP-USB500W02M-L21 [28]	ELP-USB8MP02G-L75 [29]	ELP-USB500W05G-FD100 [30]
Frame Rate	30-60 fps	30-60 fps	30 fps	15-30 fps	15-30 fps
Megapixel count	8 Megapixel	2 Megapixel	5 Megapixel	8 Megapixel	5 Megapixel
Display Resolution	1280 x 720 @ 60fps 1920 x 1080 @ 30fps	1280 x 720 @ 60fps 1920 x 1080 @ 30fps	1280 x 720 @ 30 fps	3264 x 2448 @ 15 fps 800 x 600 @ 30 fps	2592x1944 @ 15 fps 800 x 600 @ 30 fps
Focal Length	3.6 mm	N/A	2.1mm	3.6mm	3.0mm
Angle of View	60 degrees	180 degrees	Up to 150 degrees	75 degrees	100 degrees
Operating Voltage	5 V	5 V	5 V	5 V	5 V
Power Source	15 cm Ribbon Cable	USB BUS or 4P-2.0mm socket	USB BUS	USB BUS or 4P-2.0mm socket	USB BUS or 4P-2.0mm socket
Size	25mm x 24mm	38mm x 38mm	38mm x 38mm	38mm x 38mm	38mm x 38mm
Weight	3g	30g	30g	30g	30g
Cost	$25	$45	$43	$72	$34

Table 1. Camera Comparison

- Camera Module v2 [26] – The Raspberry Pi Camera Module v2 is a very versatile camera. The camera of course only works with the raspberry pi, which limits it. However, the camera module runs at a staggering 30-60 fps, which is more than ideal for our needs. The camera module has an 8 mega pixel count. Having a higher mega pixel count always means better image quality, and 8 megapixels is the most we found tied with the ELP-USB8MP02G-L75. It is able to stream video at a resolution of 1280x720 at a smooth rate of 60 fps. It also has the option to higher the resolution to

1920 x 1080, but reduces the framerate by half at only 30 fps. This shouldn't be too much of an issue however since 30fps is still a smooth rate. The only disadvantage of the camera module comes in with its' focal length. The module has a relatively bigger focal length at about 3.6mm, this means that it has an approximate viewing angle of about 60 degrees. Since our project requires us to have full coverage around the car, this could potentially pose a problem. However, since the angle is still rather large and four will be used for each side, we believe 60 degrees is acceptable to cover most of each side. It runs on 5V and is attached directly into the Raspberry Pi via a ribbon cable. It is the smallest of all the cameras and comes in at the cheapest at only $25 a camera.

- ELP-USBFHD01M-L180 [27] – This camera has a powerful framerate of 30 to 60 frames per second. Once again, this is ideal for constant streaming. The camera lacks a little however in quality, with a megapixel count at 2 Megapixel. This could mean a drop in quality. However, it does stream at a nice 1280 x 720 at 60 fps. Like the last, it has the option to bump up to 1920 x 1080 but drops the frame rate to 30 fps. The selling point to this camera is it's high viewing angle of 180 degrees. This very wide viewing angle is useful in covering the most area possible. Having 180 degrees open up the possibility of using only 3 cameras. However, having such a large viewing angle distorts the image a little to look like a fish eye. It runs at a stable 5V and can be powered by USB. It is a little larger than the module and comes in at a heftier $45.

- ELP-USB500W02M-L21 [28] – This camera is very similar to the last. It's first issue is its' limitation of only 30fps. This isn't a huge problem since it is still a decent framerate, but limits us. It has a higher mega pixel count at 5 Mega pixel, which could render a more vivid picture than the last camera. This camera is limited to only 1280 x 720 at 30 fps. It has a slightly smaller viewing angle than the previous, at around 150 degrees. The difference, however, is that because of the higher pixel count, the image may look cleaner than the fisheye look of the last. It runs on 5V and can also be powered through USB. Its' roughly the same size as the last camera but costs slightly less at $43.

- ELP-USB8MP02G-L75 [29] – The ELP-USB8MP02G-L75 is a camera with a lot of image quality. The camera runs at a relatively low framerate at only 15 to 30 fps. This low framerate, especially the 15 fps, can cause the image to look choppy and more like a slideshow. However, the camera has a high pixel count at 8 mega pixels. This means that each image taken is of a higher quality than the ones before. This allows for the insanely high resolution available of 3264 x 2448 but is limited by only being able to run at 15 fps. It can also run 800 x 600 at 30 fps, but this resolution is pretty low. Even though it is able to produce such a high resolution, the low framerate is not ideal. It has a smaller viewing angle of around 75 degrees. Like stated earlier, this viewing angle isn't the most ideal. Having a lower viewing angle has the possibility of leaving open areas. We believe that 75 degrees is high enough that most of the car will be covered. However, at

such low framerates, it may be hard to pick out the person in the image or even hard to keep track of when he is in frame and when they're out. Once again it runs at 5V through USB. This camera is roughly the same size as all the others except for the camera module at 38mm x 38mm. The price was very high for this camera at $72 per camera.

- ELP-USB500W05G-FD100 [30] – This camera seems to be like a mix of all the cameras we looked at. It has a relatively low framerate like the last at 15-30 fps. However, it has a decent pixel count at 5 Mega pixels. It too can run at a high resolution of 2592x1944 but once again can only run it in 15 fps. It has the same option as the last to run in 800 x 600 fps at a rate of 30 fps. This is a pretty low resolution for such a standard framerate. It has a slightly larger viewing angle than the last at about 100 degrees. This is a nice viewing angle as it lets us safely place 4 around a car and be able to cover all areas. It runs on 5V as do the rest, and can be powered through USB. It is the standard size as the others but comes at a pretty low price of only $34 per camera.

3.2.3 Microcontrollers

A microcontroller is a standard component used in a majority of embedded system projects. In fact, microcontrollers are used in most commercial products used almost every day including most refrigerators, washers, and other household appliances. Unlike desktop computers that can run thousands of programs at once and are more "general purpose" computers, microcontrollers are "special purpose computers" which are good running one program well [31]. Their small size and usual low power consumption makes them ideal for embedded systems.

The basic structure of a microcontroller can be separated into 9 components: CPU, Memory, I/O Ports, Serial Ports, Timers, ADC, DAC, Interpret Control, and Special Functioning Block [32].
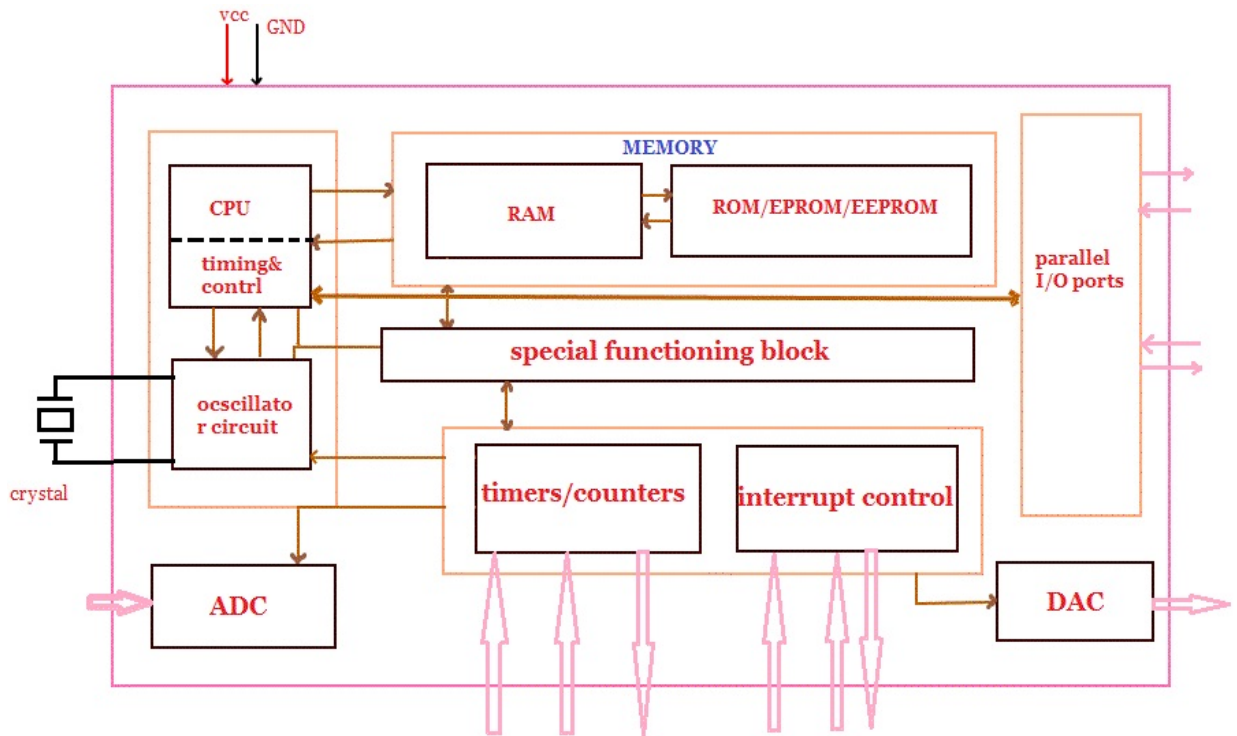
Figure 4. Microcontroller (Reprinted with permission from CircuitsToday))

- CPU – Just like personal computers, a microcontroller contains a CPU which acts as a "brain". The CPU is responsible for collecting all the data, decoding it and then putting it all together in order to successfully complete the assigned task. Most microcontroller CPUs are much more simple than standard CPUs used in most personal computers. This is due to the limited amount of information being collected and distributed when using a microcontroller computer. By limiting the power of the CPU, the microcontroller is able to stay at a low running voltage. The CPU is what connects all the components of a microcontroller into a single system [32].
- Memory – A microcontrollers memory works by having a memory chip store all programs and data. Each microcontroller has a certain amount of either ROM, RAM, or flash memory used for the storage of program source codes [32]. The memory on a microcontroller varies wildly depending on which controller one is looking for. Some microcontrollers focus on more RAM which is where data must be read and written to it repeatedly. Others focus on having more flash memory which normally stores data that in unchanging [33].
- Input / Output Ports – The I/O ports are what the microcontroller uses in order to communicate with peripherals. These ports are usually split into analog and digital. The inputs are used to read external signals while the outputs are used in order to drive devices like a LED [34].

24

- Serial ports – A microcontroller has serial ports in order to give serial interfaces amid microcontroller peripherals [32]. There is commonly only one of these ports per controller. Unlike parallel ports, serial ports only transfer in or out one bit at a time [35].
- Timers – A microcontroller may be built with one or more timers. These timers, or counters, are used to control all the counting and timing operations within the controller. Not only does the timer help in with internal counting, but could also be used to time an external pulse. Basic functions of a timer are for clock usage, frequency measuring, modulating, and making oscillations [32].
- Analog-to-Digital Converter – Microcontrollers come with a ADC in order to convert the input analog signals into digital signals. Examples of analog input devices could be different types of sensors including temperature and pressure. Analog input exists when a variable voltage corresponds to a floating point decimal value [36].
- Digital-to-Analog Converter – This is essentially the opposite of the ADC. It takes digital signals and converts them to analog. This is useful when you need to output an analog signal into an appliance, for example, a DC motor [32].
- Interrupt Control – The interrupt control is responsible for giving delayed control for a working program. These are inbuilt, but can also be external in some cases [32].
- Special Functioning Block – Some microcontrollers come with special conditions to them depending on what they may be used for. The special block has additional ports in order to carry out the special operations [32].

Microcontrollers, while all functioning relatively the same way, can be broken into categories: Bits, Memory, Instruction set, and Architecture [32]. These categories are important to consider when designing a project. Depending on the end goal of the project, different microprocessors may need to be chosen over others due to the category it falls under.

- Bits – Most microcontrollers can have three different bit numbers; 8 bits, 16 bits, and 32 bits. The 8 bit microcontrollers are the most basic and are used to execute logic and arithmetic operations. The 16 bit microcontrollers are used for greater accuracy and performance compared to that of the 8 bit. 32 bit microcontrollers are the most advanced and are used mainly in automatically controlled appliances [32].
- Memory – There are two different types of microcontrollers when dealing with memory, either External or Embedded. When an embedded structure is built with a microcontroller which doesn't comprise of all the functioning blocks existing on a chip it is considered an External Memory Microcontroller. When an embedded structure is built with a microcontroller

which compromise of all the functioning blocks existing on a chip it is considered an Embedded Memory Microcontroller [32].

- Instruction Set – Instruction sets for a microcontroller come in two types, CISC and RISC. CISC stands for complex instruction set computer. This allows for the user to apply one instruction as an alternative to many simpler instructions. RISC stands for reduced instruction set computers. This allows for reduced operation time by shortening the clock cycle per instruction [32].

- Architecture – There are two major architectures of the microcontroller: The Von Neumann architecture (or Princeton Memory Architecture Microcontroller) and the Harvard Memory Architecture Microcontroller. The Von Neumann architecture was the older of the two designs. The major differences between these two architectures are the buses. The Harvard architecture has separate data and instruction busses, which allows for the transfers to be performed simultaneously on both busses [37]. The Von Neumann architecture on the other hand has only one bus which is used for both data transfers and instruction fetches [37]. This makes for data transfers and instructions fetches to be scheduled. The Harvard architecture has the ability to have two separate memory systems. This allows for the structure to potentially be able to read from both a cache and memory simultaneously. The Harvard architecture is used more for higher performance systems due to its separate buses, however the Harvard architecture isn't always better. For example, if your system is small and only requires one shared cache, a Von Neumann architecture may work more efficiently. This is because the Von Neumann utilizes a unified cache in order to store its data and instructions [37]. The Harvard on the other hand would need separate caches for each bus, and would be inefficient to use for a single shared cache [37]. Since the Harvard Architecture has separate storage for both code and data memory, and typically code memory is read-only and data memory is read-write, it is impossible for the program contents to be modified by itself [38]. However, the Von Neumann architecture on the other hand have shared storage for the code and data, allowing it to be easily modified by itself [38].

There are dozens of different microcontrollers available on the market. They vary in cost depending on the performance of the controller. For this project, we were looking for microcontrollers that are specifically low-power, small, have enough I/O ports, and contain enough processing power while all staying relatively cheap. Some of the manufactures of microcontrollers we check out are Arduino, Raspberry Pi, Texas Instrument and Atmel.

Board Name	Arduino UNO [39]	Arduino Mega 2560 [40]	Raspberry Pi 3 [41]	MSP430G2553 [42]	ATSAM3N00A [43]
CPU	16 MHz ATmega 328P	16 MHz ATmega 328P	1.2 GHz Quad-core ARMv8	16 MHz MSP430	48 MHz Cortex-M3
GPU	N/A	N/A	400 MHz VideoCore IV	N/A	N/A
RAM	2 kB	8 kB	1 GB	0.5 kB	4 kB
Storage	32 kB Flash	256 kB Flash	MicroSD	16 kB Flash	16 kB Flash
Network	N/A	N/A	10/100 Ethernet, 802.11n/Bluetooth 4.0	N/A	N/A
Video Outputs	N/A	N/A	HDMI/Composite	N/A	N/A
Audio Outputs	N/A	N/A	HDMI/Headphone	N/A	N/A
USB ports	1	1	4	1	0
GPIO	14 x Digital I/O, 6x PWM digital, 6x Analog	54 x Digital I/O, 15x PWM digital, 16 x Analog	40 x GPIO pins	20 x GPIO pins	48 x GPIO pins
Operating Voltage	5V	5V	5V	3.6V	3.6 V
Power source	USB or 2.1mm jack	USB or 2.1mm jack	Micro-USB or pins	USB or pins	VDDCORE pins
Size	68.6mm x 53.4 mm	101.52mm x 53.3 mm	85.6mm x 56mm x 21mm	50.8mm x 66.04 mm	9mm x 9mm
Bit	16-bit	32-bit	64-bit	16-bit	32-bit
Weight	25 g	37 g	45 g	N/A	N/A
Price	$25	$46	$35	$2.50	$2.50

Table 2. Microcontroller Comparison

- Arduino UNO [39] – The Arduino UNO is a very versatile microcontroller. It runs on the 16 MHz ATmega328P processor which allows for fast transfer rates. The UNO has some of the smallest RAM out of the microcontrollers. This could pose an issue if the programs given to the Arduino are too intensive. Like most of the other microcontrollers, the UNO doesn't have an inbuilt GPU, network ability, video output, or audio output. This isn't necessary for our project but could be useful and is normal in most microcontrollers since it isn't necessary. The controller has a total of 20 GPIO, 14 being digital and 6 being analog. This isn't an outstanding amount of I/O ports, but enough for our project. It runs on a standard low operating voltage of 5V, which is ideally low for what we want. Its small size allows for easy integration with the system. It is also a 16-bit system which means for more accurate and complex instructions, but may not be able to do more complex 32-bit sized instructions. For our project, this shouldn't be an issue. The UNO also functions on any operating system allowing for easy set-up. Even though the board may not be the fastest, it's relatively cheap for what it does at $25.
- Arduino Mega 2560 [40] – The Arduino Mega 25560 is very similar to the Arduino UNO. The Mega runs on the same CPU, a 16 MHz ATmega328P, meaning it has just as fast of transfer rates as the UNO. However, the first major difference is the 8 kB of RAM. This is four times as much as the UNO, and even has 256 kB of flash memory compared to the 32 kB of the UNO. Once again, the microcontroller doesn't come with a GPU, a built-in network, or both audio and video outputs. This isn't a huge deal since most don't. The Mega really shines with how many I/O ports there are, with a total of 54 digital and 16 analog. This amount of GPIO is way more than enough for what we need. It runs at the same ideally low voltage of 5V and has the same connections. Once again the Mega differs from the UNO with its size and its 32-bit system. Being able to process 32-bit instructions is useful, but doesn't seem to be a necessity for our project. Once again the Mega is compatible with most operating systems making it very accessible. The biggest downside to the Mega is the higher price of $46.
- Raspberry Pi 3 [41] – The Raspberry Pi 3 is a very powerful microcontroller. It is relatively more powerful than most microcontrollers, making it almost in a different class. However, just because it seems more powerful, this doesn't come without side effects. Raspberry Pis are known for their ability to crash if the power supply is not set up correctly or doesn't supply the correct constant supply of voltage. This can cause for many unexpected error if not done carefully. It runs on a 1.2 GHz Quad-core ARMv8. This is an extremely powerful CPU for a microcontroller. It also comes with a 400 MHz VideoCore IV GPU, Ethernet, Bluetooth, and Wifi inbuilt, plus both HMDI/Composite video outputs and HMDI/Headphone audio outputs. The most useful of these add-ons for what we may need is the inbuilt Wifi and

Bluetooth. This will allow us to pass on buying an external adapter. It also has 4 USB ports compared to the 1 every other microcontroller has. This could be very useful since many peripherals such as cameras use USB for connection. The Pi also has 1 GB of RAM, which can be very useful especially when transferring video. It also comes the option of adding a MicroSD for easy storage. The Pi has 40 GPIO pins, which is more than the UNO, but less than the Mega. However, 40 pins are more than enough for what we are doing. It runs on the same ideal 5V, but as stated earlier, is much less forgiving than other microcontroller when dealing with power. It is at a relatively small size, slightly larger than the UNO but smaller than the Mega. It is able to process 64-bit instructions which is quadruple the amount of bits the UNO can handle. It is priced at a reasonable $35.

- MSP430G2553 [42] – The MSP430G2553 is a little simpler than the microcontrollers so far. It has a 16 MHz MSP430 CPU which allows for rather fast transfer rates. The RAM on the MSP430 is very small, at only 0.5 kB. This is very small and could possibly lead to some slower processing. It comes with 16 kB of flash memory which is half that of the Arduino UNO. Like every board but the Pi, it doesn't come with any of the additional features like inbuilt internet or a GPU. It has 20 GPIO pins, which is a reasonable amount for what we are working on. The one major advantage for this microcontroller is the low operating voltage of 3.6V. It is also pretty lenient with this, being able to run some functions at as low as 1.8V. It is a 16-bit system like the Arduino UNO which would suffice. It isn't very big and comes at a low price of only $2.50.

- ATSAM3N00A [43] – This Atmel board, the ATSAM3N00A, is another simple microcontroller when comparing with the Arduino or the Raspberry Pi. It has a rather smooth running 48 MHz Cortex-M3 CPU compared to the 16 MHz MSP430. It has a decent RAM size at 4kB, twice that of the Arduino UNO and 8 times that of the MSP430. It comes with 16 kB of flash memory which is on par with the MSP430. Just like most microcontrollers, there are no inbuilt Wifi capabilities, a GPU, or any extra outputs. Probably the worst part of the board is there being no USB access. This can become a complication since many peripherals use USB. However, it has 48 GPIO pins which is a lot of ports, second to the Arduino Mega. As stated before, there are more than enough for what we are working with. It also has a small operating voltage of 3.6V. Surprisingly, it runs on a 32-bit system which is larger than the UNO and the MSP430. It also comes at a very low price of $2.50.
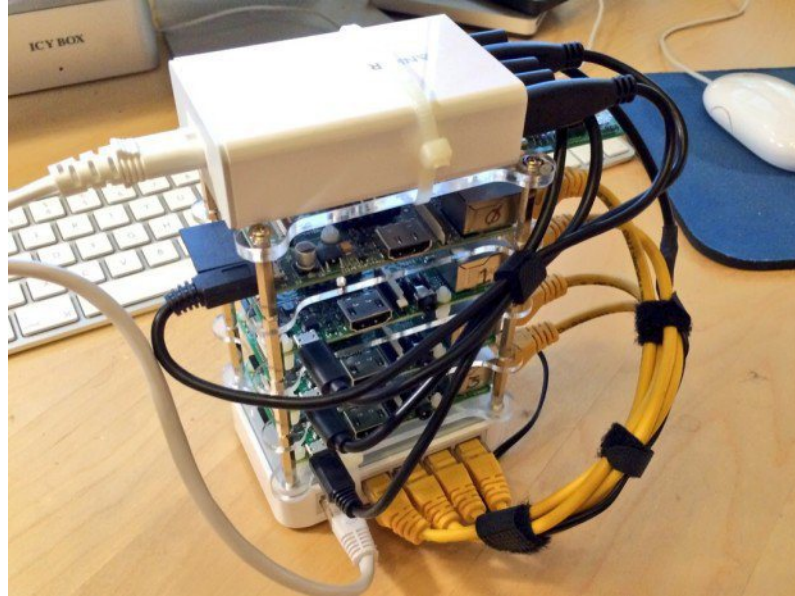
3.2.4 Raspberry Pi Cluster

Figure 5 Raspberry Pi Cluster (Permission Pending) [44]

For this project a Raspberry Pi Cluster may prove to be an efficient way to process four simultaneous video inputs efficiently. A Raspberry Pi Cluster in essence is the combination of Raspberry Pi microcontrollers and their processing power to contribute to a central process. Pi clusters are managed by the 'head' node which generally delegates the task at hand to all of its slave nodes. Each slave node processes its individual part of the whole task and contributes it back to the head node. Generally, the head node is the only one aware of the task at whole. However, as an aside, the function of these Pi clusters is most often not the 'final directive' of a major product. Simply, Pi clusters act as development and test platforms for prototyping concepts. The reason for this is the relatively cheap cost of creating a Pi cluster (at an average of $45 per Pi). As well, the fact still remains that the processing power of a Pi cannot compare to an enterprise-level multi-processing system. Therefor it makes sense to test your application on a cheaper cluster system with less monetary and overhead costs before translating it to the real thing. [45]

Parallel-Processing

It is important to note that similarly to hyper-threading in modern day CPUs, the extra parallel processing doesn't necessarily create *quicker* processing. When running an application that does not utilize the extra virtual threads provided by an i7 CPU (4 physical cores and 4 virtual cores) then the localized performance would be regarded as the same for an equal spec'd i5 CPU (4 physical cores 0 virtual cores). Simply stated, the user can only get as much out of extra parallel processing as they are able to utilize their program and process for. With respect to our project, this ideology coincides perfectly with our need to control our separated camera modules. [45]

To create a Raspberry Pi Cluster technique, there are several base requirements:

- Multiple Raspberry Pi's
- Associated Pi storage (Micro SD Card)
- Ethernet Cables for Pi communication
- USB Hub to provide power to components
- Ethernet Switch

The PI's will each communicate across the Ethernet switch by SSHing to the local IP address of each PI. Each PI will be connected to the Ethernet switch for network communication and to the USB Hub for power.

3.2.4.1 Raspberry Pi Cluster Utilizing MPICH

One procedure to set up a Pi Cluster is by utilizing MPICH. MPICH is an implementation of the MPI (Message Passing Interface) Standard. This standard is widely used in parallel processing architectures.

To create a Raspberry Pi Cluster using this technique, there are several requirements:

- Multiple Raspberry Pi's
- Associated Pi storage (Micro SD Card)
- Ethernet Cables for Pi communication
- USB Hub to provide power to components

The MPICH is a package that is easily installed onto a Raspberry Pi by following the following steps:

1. Update master node Raspberry Pi to its most recent packages.
2. Make a directory to store the MPICh package.
3. Install the latest mpich build from http://www.mpich.org/static/downloads/
4. Run the console command tar xfz <mpich .gz filename>
5. Make a directory for the MPI build install.
6. Install the gfortran package
7. Move the configure file within the MPI installation to the /home directory.
8. Add the MPICH directory to the PATH variable [46]

Once these steps are completed, the installation must be copied to each of the other slave nodes. Once each node in the cluster contains the correct packages, they can be connected via Ethernet cord to be able to SSH to each other's local IP address. To do this, the NMAP package must be installed, and the standard ipconfig command can be used to return the master node's local IP address. The command sudo nmap -sn 192.168.1.* will return all of the local IP addresses used by the other PIs. Those will be utilized to access each PI. [47]

3.2.5 Storage Devices

The Automated Vehicle Anti-Theft Security System needs to have a storage device that will hold the software and infrastructure needed for the microcontroller to activate the cameras, record, process the video, send it to the phone and delete the older video recordings. The storage device will also allow the system to store

the latest recorded videos and give the owner the opportunity to see the latest events that happened near his/her car when absent. Different storage options are being considered. The different types of storage being taken into consideration are external Hard Disk Drives (HDD), Solid State Drives (SSD), and Secure Digital Cards (SD Cards).

3.2.5.1 Hard Disk Drive (HDD)

Hard Disk Drives, abbreviated as HDD, were invented in the 1950s. They started as large disks up to 20 inches in diameter holding just a few megabytes. HDD are non-volatile memory hardware devices that permanently store and retrieve data on a computer. A hard drive consists of one or more platters to which data is written using a magnetic head, all inside of an air-sealed casing. Internal hard disks reside in a drive bay, and connect to the motherboard using an ATA, SCSI, or SATA cable [48] [49]. Hard drives are powered by a connection to the power supply unit. The hard drives being considered for this system are external. These type of storage devices are almost identical to internal HDDs with the only difference is that external drives interface with the computer over USB or eSATA S [48]. Figure 1a shows the inside of an HDD.
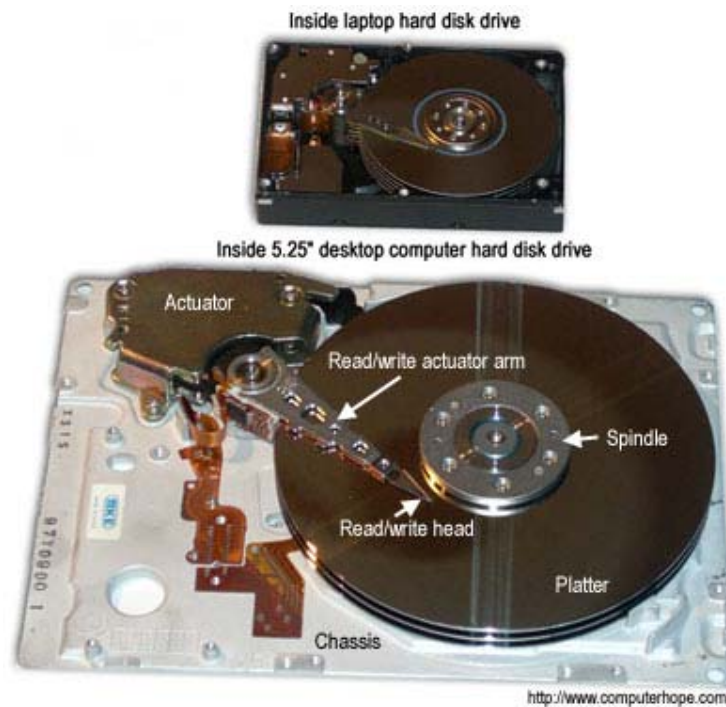

Figure 6. Inside of a HDD in a laptop and a desktop computer (Permission pending from computerHope)

A motor is used to spin the platters such as the ones seen above. As those plates are spinning, the actuator controls the position of the actuator arm read and write heads in order to read information from the platter or record data on the platter. Today, this technology has the capacity to store large amounts of data for very low price.

Nowadays, external hard drive capacity ranges from 60 Gigabytes to 1 or 2 Terabytes. For this system the storage capacity needed to hold the operating system, the software as well as video storage is at most 16GB. The most common commercial external HDDs have a capacity that is not necessary for a system such as the one we are building.

Furthermore, another metric very important when considering a storage device, it is how fast the CPU can read and write data from the HDD. Data rate is the number of bytes per second that the drive can deliver to the CPU. HDD Rates between 5 and 40 megabytes per second are common [49]. Seek time is the amount of time between when the CPU requests a file and when the first byte of the file is sent to the CPU. Seek times between 10 and 20 milliseconds are common [49].

3.2.5.2 Solid State Drive (SSD)

A Solid State Drive, abbreviated as SSD, is another storage device that is being considered. SSDs are drives that uses non-volatile memory as a means of storing and accessing data. Unlike a hard drive, a SSD has no moving parts such as magnetic heads and platters but instead have an embedded processor, also known as a controller, in charge of performing operations to read and write data on the device [50] [51]. This gives SSD the advantages such as accessing information faster, no noise, often more reliable, and consuming less power. SSD speeds range between 35-100 microseconds. This being faster than regular magnetic disk drives [51]. Capacity range from 30GB to 500GB at a reasonable price.

The first SSDs were implemented in IBM supercomputers in the 1970s. They have improved drastically in storage capacity and they are now accessible for laptop and desktop computers [52]. Because SSD have been proven to be dramatically faster than HDDs, they have a higher cost. Most common external SSDs have capacities of 20-30 GB [50]. This Automated security system requires a storage size of at most 32GB. Although, SSDs are very fast, that amount of speed and capacity that it brings also comes more expensive than other options.

3.2.5.3 Secure Digital (SD)

A Secure Digital card, abbreviated, SD card, is a non-volatile form of flash memory for portable and mobile devices. SD cards are located in thousands of consumer electronic device models including phones and digital cameras. SD cards come in several sizes MicroSD (15 mm × 11 mm), MiniSD (21.5 mm × 20 mm) and SD (32 mm × 24 mm) [53].

SD cards provide large-capacity storage in a tiny package with very low power draw, this crucial because SD cards are often used in battery powered devices such as the security system we are crating. SD cards also provide a broad range of storage capacity from some Megabytes to hundreds of Gigabytes. Next generation of SD cards, known as SD eXtended Capacity (SDXC), can hold up to 2 TB (2000 GB) of data. SD data transfer speeds range from 2 Megabytes per second from the SDHC generation to approximately 90 Megabytes per second

from the SDXC generation of SD cards [53] & [54]. Microcontrollers taken into consideration for this project have built-in modules that support SD cards for storage purposes.

3.2.5.4 Comparing Different Storage Options

Now that the three different storage devices have been described, they are going to be compared on the several metrics to decide which one is ideal for our system. The factors that will be taken into account will be portability, capacity, read/write speed rate and price. HDDs with large capacities could be acquired for a very good price. The capacities of HDDs can range from 50 GB - 1TB. SSD drives are more expensive that HDDs but are attainable when it comes to sizes of 64 GB - 128GB. SD cards are the cheapest ones when it comes to portability and capacity. SD cards do have storage capacities of up to 128 GB. The storage capacity for this system would not exceed 64 GB so buying a large HDD or SSD of such size would not be ideal because that amount of storage would not be fully used.

The read/write speed rates for SSDs are the highest among the three options. SSD speeds can be 350 MB/s. HDD speeds can range between 50 – 120 MB/s. SD Cards have speeds commonly ranging between 10 MB/s – 40 MB/s. SD Cards. SSDs without doubt have better read and write performance than any other of the two options.

In regards to portability, external HDDs and SSDs are available and most of them are available with USB or SATA interfacing. SD Cards on the other side have their own interfacing card reader that is commonly built in the computers and microcontrollers, making the integration between components seamless. MCUs that are being taken into consideration, such as the Raspberry Pi, have a built-in SD Card reader that allows the users to store the OS, files and software that the microcontroller can read and accessed once the card is inserted in the slot. SD cards, especially MicroSD Cards, also have smaller dimensions than the two other options and that is why it has been popularly known to be the storage option in several portable electronics such as smartphones, cameras and video recorders.

Price among these three options depending on the speed and capacity of the device. SSDs are attainable if their speed is of 64 GB or lower. These types of devices have been described "attainable" when talking about computers and laptops. SSDs improve performance on such systems and it is worth spending $60 – 70 to improve storage performance. In the case of an outdoor security system, SSDs would improve performance gradually but they are not in the price range necessary to stay under budget. SD cards have sufficient capacity for our system and can be attained at a fair price to remain under the planned budget.

3.2.6 Wireless Communication

In order to interface with the security system, the primary procedure will be to have a direct communication link between the central device located atop of the vehicle and a mobile device, most commonly running Android, iOS, or Windows 10 mobile. Additionally, the central device will have capabilities to connect to the World Wide

Web, in this section we will investigate the various communication techniques with respect to the hardware that we have access to include in our project. The three primary means of wireless communication available to us are Bluetooth, wi-fi, and GSM.

3.2.6.1 Bluetooth

Bluetooth is often seen as the closest-range of the three, although this is not always the case. There are 3 classes of Bluetooth devices, with potential range varying from 10 meters to 100 meters. The expected caveat to this is the expected power required to utilize the module or device is increased in line with the provided range capability. Due to the nature of our project and reliance on Solar Power with a need to conserve power as efficiently as possible, we must remain aware of our power needs and make trade offs as needed. The transfer rate of Bluetooth is also on the lower end which makes it a poor option to accomplish one of our core project requirements of providing a live video feed to the user. The greatest benefit of using Bluetooth as a means of communication is how simple it is to use from the perspective of the consumer. All that's required is a Bluetooth capable device and possibly a hardware button to enable pairing-mode. The user is quickly able to pair to their device and begin the interfacing process. [55]

Bluetooth4.0 Hm-10 Master Slave Module

The HM-10 Module is a Bluetooth module that has the capability for use with both of our core microcontroller choices, the Arduino and Raspberry Pi, making it a viable option.
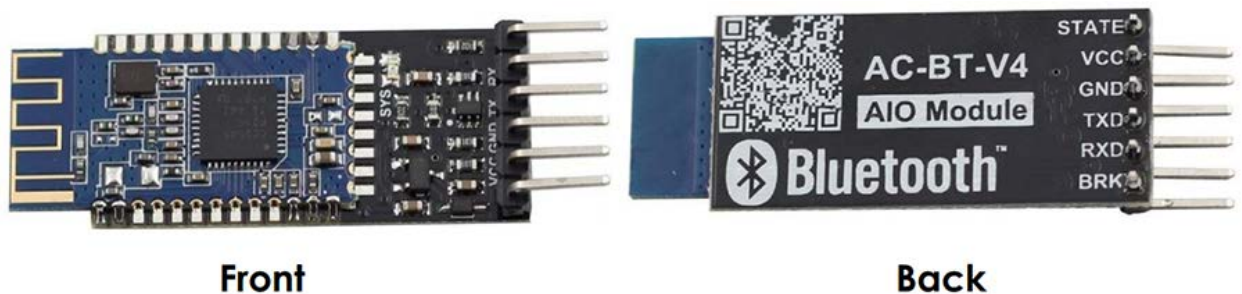

Figure 7. Bluetooth 4.0 HM-10 (Permission Pending) [56]

The module uses Bluetooth low energy (BLE) which is a very common Bluetooth technology primarily used in low-power embedded devices. The module's main characteristics are BLE V4.0 Bluetooth Specification, USB 2.0, and a transmission rate of 6 kbps. The HM-10 can be connected with ease to an Arduino board and communicate with an Android device via the BleSerialPort application. [56]

Raspberry Pi 3 Model B Onboard Bluetooth

The Raspberry Pi 3 Model B microcontroller priced at ~$35 includes an onboard Bluetooth & Wi-Fi component.
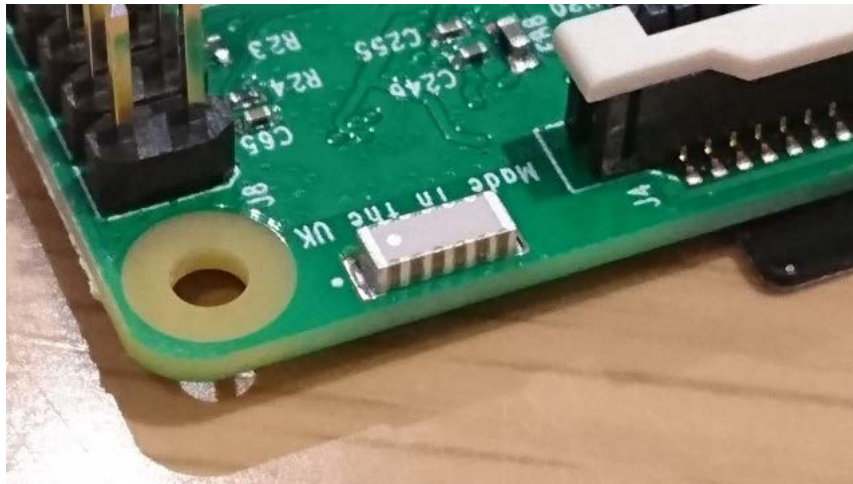
Figure 8. Raspberry Pi Bluetooth / Wi-Fi Component (Permission Pending) [57]

One major benefit of utilizing a Raspberry Pi microcontroller as part of our project is the onboard support of both Bluetooth and Wi-Fi connection. With this, there is also the plethora of online knowledge and tutorials on how to set up the required routines to initiate Bluetooth connection. To configure the Bluetooth device, once Raspbian is installed onto the board it's easy as entering the command `sudo apt-get install Bluetooth-pi` into the console. Once the Bluetooth support is installed, the user can then enter bluetoothctl to display the Bluetooth commands available, such as 'scan <on/off>' to scan for devices and 'pair <device>' to pair with a device. The available commands are very helpful and intuitive for a developer to initiate a connection programmatically. [57]

3.2.6.2 Wi-Fi

The next wireless technology that this project is investigating the use of is Wi-Fi. This communication technique would allow our device to connect to the internet via a wireless Local Area Network (WLAN). Using this technology would enable the security system to connect to the internet through the user's home router or a publicly available network. The greatest benefit of this technology is the potential of an extremely high relative throughput. Accordingly, the greatest con of this technology is its limited range of use. When the chosen vehicle is parked in proximity of the user's home, the ability to connect to the wireless network is relatively easy and expected. However, when parked in an area without access to public wi-fi, the system is left largely in the dark. One of the saving graces of using this type of communication is, similarly to the requirement of a mobile device, the recent wide-spread presence of public wi-fi offerings. From Publix to Five Guys and Home Depot, a public wi-fi connection is almost expected in most well-populated areas.
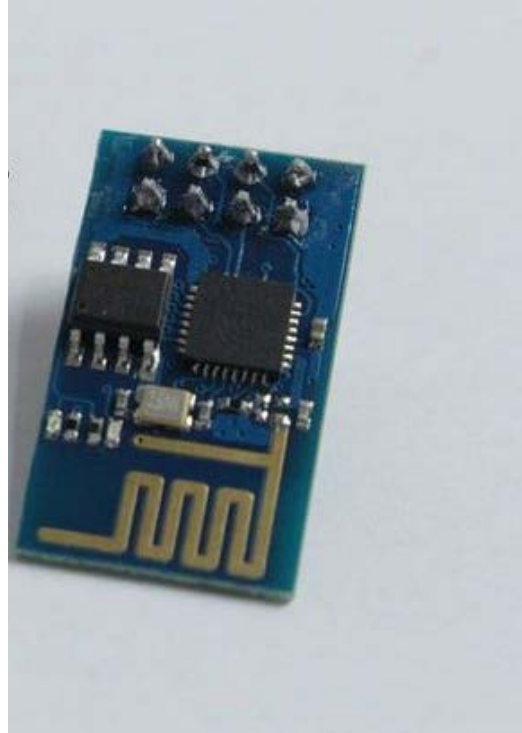
ESP8266 Module

The ESP8266 Wi-Fi module can be used with an Arduino board to create Wi-Fi capabilities. It contains the ability to handle all of the Wi-Fi networking processing for a microcontroller and comes programmed with AT commands. The onboard processing allows it to communicate effectively with the Arduino board and there are countless online resources dictating how to initiate this process. [59] The ESP module requires a voltage of 3.3 to function correctly and contains pins that are used to interface with the Arduino microcontroller. The following pins are available for use:

VCC – Voltage Input

GPIO – Programming ports

CH_PD – Power Enable

RST – Reset

GND – Ground Pin [58]

Raspberry Pi 3 Model B Onboard Bluetooth

Using the same exact component on the Raspberry Pi 3 Model B, we are able to connect via Wi-Fi and initiate an internet connection. In this case however, Wi-Fi is supported if the OS is up to date. Within the directory */etc/wpa_supplicant/wpa_supplicant.conf* the file can be edited to supply both the SSID and the access password to setup credentials. Once the credentials are entered, the wireless connection will in most cases be initiated automatically. If the

37

process is not done, then restarting the wireless connection via `sudo ifdown wlan0` and `sudo ifup wlan0` can re-initiate it. [57]

3.2.6.3 GSM Mobile Communication

Utilizing connection to a wireless service provider via an embedded GSM chip would give our device the largest effective range among our available options. Instead of a virtual tether to the user's local mobile device, a home router, or a public Wi-Fi network, the limitation is instead only on the cell phone towers of the provider. This would allow the user to have access to their security system in situations where they are both located in a more remote location, and also far from the security system. GSM, or Global System for Mobile communication, is the most popular means of cellular communication. With respect to an embedded device, it can be used to send and receive SMS text messages and phone calls or connect to the internet.

In order to take advantage of a wireless-enabling GSM module, a SIM card is often required. A Subscriber Identity Module (SIM) card commonly stores the accounts contact and calendar data as well. [60] The four basic types of SIM cards are:

- Consumer white SIM card - the most commonly used type which is also often used in embedded systems due to its widespread presence.
- Enhanced ruggedized plastic SIM card - as its name suggests, a more rugged card that is designed to be more temperature and warp resistant.
- 3FF SIM - Third Form Factor, a smaller form factor card designed to be used for even smaller embedded devices
- eUICC - embedded Universal Integrated Circuit Card - This card replaces the standard removable SIM with an permanent integrated chip. The advantage of this type of card is its ability to connect to the internet directly from factory production. As well, profile and provider information can be updated Over-The-Air (OTA) which results in a more streamlined approach to connectivity.
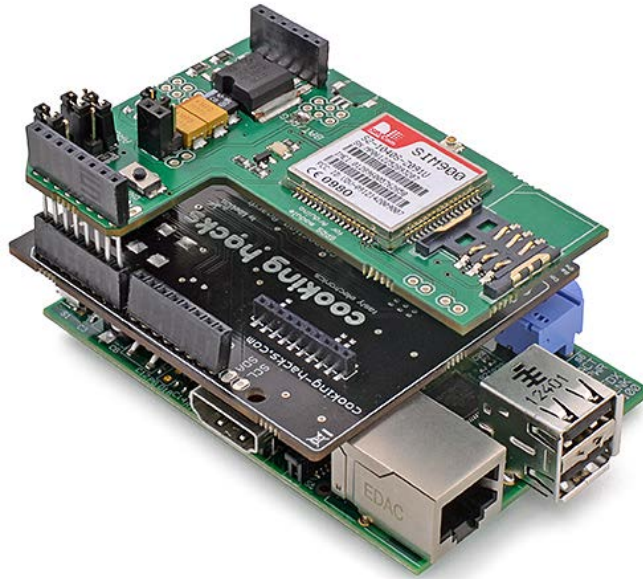
Figure 10. SIM900 module with Raspberry Pi (Permission Pending) [61]

The GPRS / GSM Quadband Module can be interfaced with a Raspberry Pi to provide GSM communication. The module contains a slot for a SIM card to complete access to the cell phone service provider's account. The card allows a plethora of communication and status verification, such as AT commands to verify either the working communication or locked status. [61]

USB Modem W/ Raspberry Pi via Point-to-Point Protocol

Figure 11. Raspberry Pi 3 Model B with a Huawei LTE USB Modem (Permission Pending) [62]

39

Using an unlocked GSM USB dongle, we are able to setup a GSM internet connection with a Raspberry Pi along with the use of an activated SIM card. The process of setting up this system is as follows:

1. Verify Raspberry Pi packages are installed correctly, namely the following:
   - Point-to-Point Protocol daemon
   - USB_ModeSwitch
   - USB_ModeSwitch_Data

   These can be installed using the console command:
   `sudo apt-get install ppp usb-modeswitch usb-modeswitch-data`

2. Configure the Huawei dongle to act as a modem, this can be done using the packages above and by editing the */etc/usb_modeswitch.conf* file. First, retrieve the vendor and product ID from the module by entereing the `lsusb` command.
   Using the output we define the DefaultVender and DefaultProduct field for use with the USB_ModeSwitch package.

3. Configure Point-to-Point Protocol daemon package. This can be by entering the commands to enable the PPP interface and add a configuration file to */etc/ppp/peers/gprs.conf* defining the user and connect fields.

4. Start Point-to-Point Protocol interface via the `ifup gprs` command.

5. Complete. The dongle is now set to act as a modem using the included SIM card and will automatically attempt to connect. [62]

Effective Range, Transfer Rate, and Overhead Cost

Each of these three primary means of communication between our surveillance device and the users personal device each have their own strengths and weaknesses. Bluetooth generally has the lowest effective range and transfer rate, however is relatively straightforward to use, develop, and once connected, maintain communication. This makes Bluetooth very good for such things as settings configuration and games and/or systems that have small data throughput requirements, such as simple puzzle games and state machines. Wi-Fi on the other hand would relatively have the highest potential transfer rate, due to the use of nearby networking router devices. Its effective range can be increased with longer-range antennas and wi-fi extenders surpassing the limited Bluetooth capabilities.

As an aside, we do have to consider the limitations of Wi-Fi access. Within range of the user's home, it would be relatively straightforward and reliable to connect to a standard home wi-fi system however much more difficult when parked in a public area that may or may not have public use Wi-Fi. Even in the case of an available connection, many places require a "guest sign-in" to verify the user which would complicate the authorization process. The final possibility is the use of the GSM module. The range would by far be the most flexible, to an almost universal degree. As well, the potential transfer rates would be high enough to support video streaming, depending on the area of connection availability. This does, however, follow with the highest level of overhead cost both monetarily and in development

time and effort. The requirement of an activated service with a SIM card as well as the fact that there are less available resources for development and research between Pi -> GSM -> Android communication raise the overhead requirements considerably.

Wireless Technology	Effective Range	Transfer Rate	Overhead Cost
Bluetooth	Low	Low	Low
Wi-Fi	Medium	High	Medium
GSM	High	Medium	High

Table 3 Wireless Technology Comparison

3.2.7 Sensors

3.2.7.1 Motion Sensor

Among the peripherals for our project we have sensors. Specifically, motion sensors. Our design consists of several cameras covering a full view of a vehicle. These cameras are implemented in order to capture someone who is potentially trying to break in the car. The problem that comes up with this is how do we make sure the cameras aren't filming all of the time, but only when something is in a reasonable enough area to start recording. In order to try and solve this problem we will try to implement a system of sensors, the first being initial motion detection. There are several different types of commonly used motion detection: Ultrasonic, Microwave/CW (Continuous Wave), Image Processing, and PIR [63].

Ultrasonic

An ultrasonic sensor is a sensor that emits a sound pulse that reflects off of objects entering the wave field. The then reflected "echo" is then picked up by the sensor. The detection of the sound back to the sensor then generates an output signal [64]. These sensors fall into the category of active sensors since the sensor found on the front of the device is actively emitting sound waves at ultrasonic frequencies. Since it's having to constantly emit sound waves, the sensor requires a continuous supply of energy [63]. This means that implementing an ultrasonic sensor could draw on unwanted power. The unique part of ultrasonic sensors is how the time for an ultrasonic sensor's beam to strike a target and return is directly proportional to the distance of the object [64]. This allows for easier management when deciding a detection distance. They have a continuous detection field which is un-segmented which eliminates dead zones where small movement is not picked up [63]. However, it isn't good at detecting movement on materials that absorb sound and are usually pricier [64].

Microwave/Continuous Wave

Both the microwave and continuous wave sensors work in similar ways. These sensors generate an electromagnetic (RF) field between a transmitter and a receiver to create an invisible volumetric detection zone [65]. Similar to the ultrasonic, the microwave and continuous wave sensors work by sending out a wave and having it being received, with any anomalies in the detection zone setting the sensor off. Just like the ultrasonic also, these sensors are considered active sensors since they are in need of a constant supply of energy in order for the sensor to keep the detection field up [63]. An advantage of these are they don't get hindered by sound absorbing materials and are also resistant rain, fog, wind, dust, falling snow, and temperature extremes [65]. However, they are known to usually be pricier than even that of the ultrasonic sensor and more energy expensive [63]. They also need both a transmitter and a receiver, which for our project would complicate things.

Image Processing

Image processing sensors are relatively new when comparing to other motion detecting. These are sensors based on image processing that are usually used in occupancy sensing applications. Most of these sensors are several video cameras set up looking a certain direction. The video feed can then me image processed in a control and processing unit to detect human occupancy. This set up is also considered active since for this to work, the video cameras must be on and recording at all times to detect human movement. This system is usually very accurate and can be used for far more uses than the other sensors since it detects actual imagery. However, the major disadvantage of these sensors is the very high initial setup cost. [63]

PIR

The last of the motion detecting sensors is PIR or Passive Infrared Sensor. These are the most widely used sensors in the market. This is due to their utility, energy savings, and cost savings [63]. A PIR sensor measures infrared light emitted from objects that generate heat in its field of view [66]. This means that whenever an object that emits infrared moves into the detection zone, the sensor goes off. Luckily for our project, since we are dealing with detecting humans who emit infrared due to our body temperature, this sensor will work as intended. Since infrared radiation exists in the electromagnetic spectrum at a wavelength that in longer than visible light, it is invisible to our eyes [67]. However, this doesn't mean it can't be detected. This is a big advantage since, like the other sensors, there isn't a visible light giving away the detection zone of the sensor, allowing for potential suspects to not know when they are being detected. Not only do PIR sensors detect the difference in raised temperature, but are also capable of detecting something if it's temperature is much lower than the ambient temperature and the object is moving [68]. One of the major advantages of the PIR sensor compared to other commonly used motion detection is its passive energy component. This means that it is not actively emitting energy in order to detect motion [63]. This means that the device can be constantly "on" and detecting, but won't be wasting much energy. This is extremely useful, and is a major reason

Passive Infrared sensors are the most commonly used sensors. For projects using batteries or a limited amount of power, like ours, PIRs work fantastically. The reason these sensors are able to work while still being passive is due to their two main components: The Pyroelectric sensor and the Fresnel Lens [67].

- Pyroelectric sensor – The pyroelectric sensor is made up of a crystalline material that generates a surface electric charge when exposed to heat in the form of infrared radiation. The amount of radiation varies depending on the amount of radiation that is striking the crystal. These small changes can be measured using a very sensitive FET device in the sensor itself. The range of radiation associated to being the most sensitive to human body radiation is around 8mm to 14mm. However, the crystalline material is usually very sensitive to a wide range of infrared radiation. To solve this, there is usually a filter window added to limit the detectable radiation to just that of human body temperature. Most PIR systems have two sensing elements within it. These two elements are connected in a voltage bucking configuration. This arrangement allows for signals caused by either vibration, temperature change, and sunlight to be canceled out. In order for the PIR to work, an object must pass both sensor elements. Passing the first sensor and then passing the second sensor will activate the system. If both sensors are triggered at the same time, say do to a sudden temperature change in the environment, they will cancel each other out and the system will not activate. Because of this, the object must move horizontal across the sensors for them to go off. [67]
- Fresnel Lens – A Fresnel lens is the lens used on the front of the PIR sensor in order to capture the radiation and focusing it to s smaller point. The Fresnel lens is a Plano Convex lens that has been collapsed on itself to form a flat lens that retains its optical characteristics but is much thinner resulting in less absorption loss. The lens both captures more infrared radiation while also focusing it to a small point. The focal point moves across the sensor, exposing one element at a time. Though the Fresnel lens will give the best possible performance, there are other lens that can be used to extend the range. [69]

As stated earlier, PIR sensors are only active when the object is moving. This is due to them having the two sensing elements in them that only go off when both are activated a moment after each other. Unfortunately, this means for a possibility in not picking up the object. If the object is moving either too slowly or directly at the sensor, the two elements might read the situation correctly and register as picking up nothing. However, this is a small problem when comparing to all the different advantages that come from PIR. The advantages and disadvantages can be compared below:

Advantages	**Disadvantages**
Low power consumption (passive	Insensitive to slow movement
Low Price	Insensitive to movement towards sensor
Compatible with Microcontrollers	Not good at detecting at certain temperatures
Small compact size	
"Invisible" detection zone	

PIR Sensor Model	HC-SR501 [70]	DSN FIR800 [71]
Operating Voltage	5 V	5 V
Size	32mm x 28mm	32mm x 28mm
Price	$5	$8

Table 4. Sensor Comparison

3.2.7.2 IMU

Our project will require the use of an IMU or Inertial Measurement Unit. These are sensors that are able to detect when the object the sensor is placed upon moves. There are two major types of IMU, a gyroscope or an accelerometer. Though they can be used to measure the same dimensions, both have their respected purposes.

Gyroscope

A gyroscopic sensor is mainly used to detect angular velocity. If a wheel is attached to a rod and spun horizontally, the wheel would stay up. The velocity of the wheel spinning in rotation around an axis is called angular velocity. This can be measured in either revolutions per second (RPS) or degrees per second (°/s) [72]. A gyro-sensor is used in order to detect this angular velocity. In the example of the tire, the axis of rotation would only be the z-axis. Most gyroscope sensors, however, are built to be able to detect all three axes: X, Y, and Z. It is also important for gyroscopic sensors to be able to not just detect that there is an angular velocity, but which direction, clockwise or counter-clockwise, it is spinning [72].

Most gyroscopes are used in products that don't rotate constantly. By having just small rotations at a time, the gyroscope is useful in detecting the small changes

and adjusting as needed [72]. Most gyroscopic sensors sense angular velocity from the Coriolis force applied to a vibrating element [73]. Because of this, the accuracy for a gyroscope is highly dependent on the elemental material and structural differences. The characteristics most sought after when dealing with a gyroscope are:

- Scale Factor
- Temperature-Frequency Coefficient
- Compact Size
- Shock Resistance
- Stability
- Noise Characteristics [73]

In order for manufacturers to meet these needs, they turn to different materials and structures. Some of the most used materials include crystal, ceramic, and silicon [73]. Each of these elements are then arranged into different structural shapes.

Accelerometer

An accelerometer is essentially an electromechanical device that measures acceleration forces. The forces can be either static (e.g. gravity), or dynamic (e.g. moving or vibrating the accelerometer) [74]. Unlike that of the gyroscope, an accelerometer cannot detect angular velocity. Likewise, the gyroscope is unable to detect acceleration forces, only rotation. Because of this, it is sometimes more useful to use an accelerometer over a gyroscope. An accelerometer can also be useful in measuring the angle the device is tiled with respect to the earth. It accomplishes this by measuring the amount of static acceleration due to gravity [74]. This can be useful in many different instances. An accelerometer can be built in several different ways. Two of the most common ways are using the piezoelectric effect and sensing changes in capacitance.

- Piezoelectric – One of the major advantages of the piezoelectric accelerometers are that they a self-generating devices; meaning that they don't require any external power in order to generate a signal [75]. A piezoelectric accelerometer uses piezoelectric materials, which are usually very tiny crystalline structures. When an accelerative force is applied to these structures, they are then stressed and produce an electrical signal proportional to the amount of stress. The advantages of these accelerometers include exhibiting a wide linear frequency range, large amplitude ranges, and excellent durability [75].
- Capacitance – A capacitive accelerometer operates differently than the piezoelectric. The capacitive accelerometer works be measuring a change across a bridge [75]. The sensing element consists of two parallel-plate capacitors acting in differential mode. With this structure, the capacitance between the two capacitors is measured. Once an accelerative force is applied to the structure, the two parallel plates are moved apart and an alternative peak voltage is generated by the oscillator. The detection

circuits than capture the final peak voltage and the final output signal is processed [75]. Unlike the piezoelectric accelerometer, the capacitive needs a power supply to run it. The advantages of a capacitive accelerometer include their ability to measure low-level and low-frequency acceleration while being able to withstand high shock values. However, their high-frequency is limited [75].

Just like the gyroscope, accelerometers are built with different qualities. Not only are they built different ways as discussed before, but they are also built with different requirement in mind. When searching for an accelerometer, these are several things we will need to consider:

- Analog vs Digital output
- Number of Axes
- Maximum Swing
- Sensitivity
- Bandwidth
- Impedance/Buffering issues [74]

Since both the accelerometer and the gyroscope are useful in measuring different types of forces, it's advantageous to combine the two. There are many different IMUs that combine many different sensors. For our project, we looked into an IMU that could sense the vibration of someone opening a car door.

IMU Model	BerryIMU [76]	BMI160 Shuttle Board [77]
Supply Voltage	3.3 V	1.2 – 3.6 V
Sensitivity	8.75, 17.5, 70 mdps	16384 LSB/g
Acceleration	±2g, ±4g, ±6g, ±8g, ±16g	±2g, ±4g, ±8g, ±16g
Axes	6-axis	6-axis
Output Type	Digital	Digital
Weight	3 grams	N/A
Size	17.4 mm x 34.25 mm	20.32 mm x 43.18 mm
Price	$25	$37.50

Table 5. IMU Comparison

- BerryIMU [76] – The BerryIMU comes with a lot of utility. It is one of the cheapest IMU we looked at, at a low price of only $25. It comes at a very

small compact size of only 17.4mm x 34.25mm. This allows for the IMU to be integrated very easily with our design. It has a digital output which is ideal for what we are wanting in our project. It also measures on 6 axes, which means that it can measure not only the acceleration forces on the X, Y, and Z, but also the rotational forces. It runs on a low supply voltage of only 3.3V. It has a very good range of acceleration and a low enough sensitivity for what we want. This IMU is also set to work with the Raspberry Pi.

- BMI160 Shuttle Board [77] – The Shuttle Board is similar in a lot of ways to the last IMU. It also has a relatively small size at only 20.32mm x 43.18mm. It price is slightly more expensive at $37.50. However, it also has a digital output and also measures on 6 axes. It has the ability to run on as low as 1.2V which is very low. It has a pretty good range for the accelerometer and a low enough sensitivity for what we want. This board isn't specific to any microcontroller.

3.2.8 Speakers

A major factor in a security system is having a way to deter whatever is breaking the security. For most already implemented security systems there is a loud noise used in order to deter. This noise indicates that the person at fault has been caught and should back away. In order to create a noise, audio speakers must be implemented. Audio loudspeakers come in all different shapes, sizes, and most importantly quality. In order to ensure the quality of the speaker, there are several factors that one must consider. The main specifications to pay attention to in a speaker are: The Frequency response, Sensitivity, and Impedance [78].

Frequency Response

The human ear is not a perfect thing. Everyone has a different range of frequencies in which the can hear. The frequency response of a speaker is a specification that covers the range of frequencies that can be produced by that speaker. It is believed for humans that 20 kHz is the highest frequency we can hear. However, realistically most people don't hear the piercing frequency, especially as we age [78]. The deepest sounding and lowest frequency humans can hear is around 20 Hz. However, just like before, realistically any frequencies below 30 Hz tend to be felt much more than they can be heard [78]. This range, 20 Hz – 20kHz, is considered the maximum range a speaker can produce. Most speakers don't offer the extent of this range however. An important measurement to note is the decibel level. Not only does the frequency response deal with a range of frequencies, it also comes with a decibel range. Decibels are used to measure how loud the speaker can get [79].

The decibel range is given in a plus/minus deviation and can be used to determine how far the sound deviates from a neutral or "flat" response [78]. The decibel can be defined as a logarithmic way of describing a ratio [80]. The reason decibels are useful is because instead of having large arbitrary numbers associated with levels of sound, a logarithmic ratio is much more useful and easier to understand. Since

it is a logarithmic ratio with base 10, decibel levels increase exponentially. This means that the lower the number the better. Typically, speakers will have a decibel ratio of ±3dB. For every 10 decibel level increases, the noise is twice as loud [79]. Speakers having a decibel rating around ±10dB is not ideal.

A better indication of the frequency response is by looking at the frequency response plot. This plot can be generated by using a calibrated microphone and placing it in front of the speaker. A frequency vs amplitude plot is then created using certain software [81]. A predominately flat plot is ideal, meaning that the speaker will produce each tone at relatively the same level. Another important factor in the frequency response is the wattage or power being consumed. The wattage of a speaker is important to the frequency response since the decibel levels are usually correlated with how much power is being outputted. For speakers, there are two factors given dealing with wattage:

- Nominal Power – Manufacturers use this to specify what a speaker can handle long term without being damaged [79].
- Peak Power – Manufacturers use this to specify what a speaker can handle in short bursts without being damaged [79].

Sensitivity

Unlike the frequency response, the sensitivity factor of a speaker describes nothing about the sound itself but rather gives an idea of how efficient a speaker is [78]. It can be defined as the speakers' ability to effectively convert power into sound [82]. Traditionally the method to measuring sensitivity is by using the standard 1 watt/1 meter. This is measured by placing a microphone 1 meter away from the speaker and measuring the sound output in decibels with 1 watt of sound playing through it [82]. The sensitivity of a speaker is given by a value in decibels. If for example a speaker has a sensitivity rating of 85 dB, this would mean that the volume was measured at 85 dB by a microphone placed 1 meter away from the source given an input of 1 watt. Below are examples of typical decibel levels with 0 dB being the threshold of hearing [82]:

- Whisper – 15-25 dB
- Speaking Voice – 65-70 dB
- Rock Concert – 120 dB
- Pain Threshold – 130 dB

The average speakers' sensitivity is around 83-87 dB. As the decibel level increases by only 3 dB, the power needed to maintain the increase is doubled [82]. This means that finding anything above 90 dB is very rare and very high quality.

Impedance

Similar to the sensitivity, the impedance doesn't describe anything about the sound quality itself but rather how much strain the speakers place on an amplifier [78]. A general definition is impedance is the speakers' resistance to power or impeding the flow of power [82]. Impedance of a speaker is measured in ohms. This is because the impedance is essentially the resistance of the speaker gives to the

voltage and current being supplied to it [83]. Impedance however isn't a static variable in reality. The impedance of a speaker changes based on the frequency of the signal that is being put through it. Music has many different simultaneous frequencies at once, and because of this, many manufacturers will show the "nominal" impedance. The nominal impedance is essentially the lowest amount the speaker will dip down to in resistance to the load applied at any given frequency within the operating range [83]. Loudspeakers' impedances can range from 2 ohms to 16 ohms. The most common impedance rating is 8 ohms [82]. This impedance is considered an "easy load" [78]. Some higher-end speakers come with an impedance level of 4 ohms. These are usually higher quality speakers and require an amplifier that can handle the extra load. Since most good quality amplifiers can handle this load, 4 ohms is ideal.

Model	USB Powered Speakers [84]	Logitech 3.5mm Jack Compact Laptop Speakers [85]
Operating Voltage	5 V	N/A
Frequency Response	100 Hz – 18 kHz @ 3Watts	80 Hz – 18 kHz @ 5 W-10 W max
Impedance	4 Ohm	≈8 Ohm
Sensitivity	≈83-87 dB	88 dB
Dimension	69mm x 80mm x 85mm (One Speaker)	86mm x 232mm x 116mm (One Speaker)
Price	$10	$16.68

Table 6. Speaker Comparison

3.2.9 PCB Research

There are two main types of regulators found that would be best for our design: switching and linear regulators. We will discuss these types to find which is best for our design. This is relatable to charge controllers as in one type is more efficient but is more expensive than the other type.

Linear regulators are used only to step down voltage which is all that we need for our project. The main problem with linear regulators is that they are inefficient. They are typically small which is good so they can be easily integrated into our PCB design, also they are cheaper than switching regulators. One main point to make though is that linear regulators can reduce the battery cycle time because of the inefficiency but this may not be a major concern because if it found that too

much power is being lost in the regulator and the battery cycle time is heavily impacted, we can simply put an identical battery in parallel with the one being used right now which doubles the storage capacity and compensates for any losses in the regulators and charge controller [86]. Switching regulators on the other hand are more efficient but require more complex exterior circuitry. They also produce excess noise from the switching which could be a concern with other components on the PCB [86].

It was found that no practical regulators for our design would meet the requirement of supplying possibly up to 11 amps of current to the load at a time. Because there are no regulators that fit our budget and space constraints that can supply this high current. It was decided that four smaller regulators would be used to satisfy our constraints with each using up to 3 amps. We will give each Raspberry Pi module it's own step down regulator making the current demand much lower for each regulator and if an Ethernet switch is used, it uses minimal current so it can share a regulator with the Raspberry Pi modules. The linear regulator was chosen because it is the only practical type of regulator that can stand 2.5-3 amps of current at a time. The cost for these regulators was found to range from 2-10$, while the switching regulators price ranged from 30-45$.

As mentioned, the efficiency could be a concern and it was estimated at different Output currents using by first finding the power loss from the following equation where V_{in} = , V_{out} = 5 volts and I_{out} ranges from 0-2.5 amps [87]:

$$P_{loss} = (V_{in} - V_{out}) * I_{out} \quad \textit{Equation 1}$$

Then the values found for P_{loss} were plugged into the following equation [87]:

$$Efficiency = \frac{P_{Output}}{P_{Output} + P_{loss}} \quad \textit{Equation 2}$$

To better understand the estimated efficiency of our regulator, a graph was made for the efficiency against output voltage showing a linear decrease in efficiency as the output voltage gets higher:
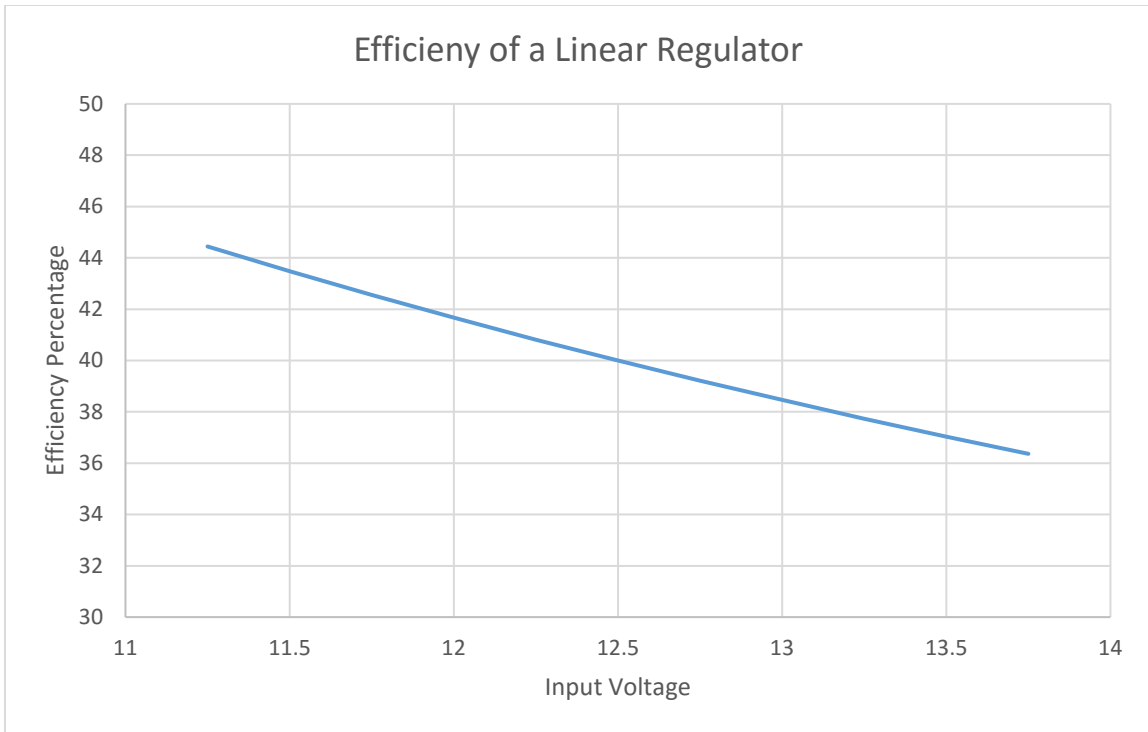
Figure 12 Graph of Input Voltage vs. Efficiency

This graph shows the change in input voltage and how this will effect efficiency, either way, there is a large loss of power. The efficiency ranges from 36-45%. As previously mentioned, a good way to compensate for this power loss if by adding another battery a short term solution.

3.3 Software

3.3.1 Android vs iOS vs Win 10

The three operating systems that have the main stranglehold on the mainstream mobile device market are Android, iOS, and Windows phone. As of 2016, the market share had Android at 84.3 %, iOS at 13.4%, and Windows mobile at 1.8%. [88] The combination of the three leaves just half a single percentage point of the market available to the remaining operating systems in circulation, namely Blackberry and PalmOS.

Android

The most widely used mobile operating system is available for development completely open source. This means that any user and any manufacturer is able to access and modify it to fit their personalized needs. This is a core reason for its popularity, the ability to be molded to the developers very needs. One of the greatest strengths of this OS is the fact that it is built on top of the Linux kernel. And with that brings the advantages of efficient process and memory management, a streamlined driver development model, file system management, network

communication, and user account. These low level functions and processes are handled at the kernel level, extremely close to the hardware level itself. [89]

Developing in Android primarily uses the Java programming language and the Android API. Google officially supports two IDEs (Integrated Development Environment), Android Developer Tools and Android Studio. However, there exists the option to use many third-party IDEs as well as other programming languages such as C# and Ruby. [90] To publish to the Android Play store, the developer must pay a one-time fee of $25.

iOS

Developing an iOS mobile application will involve using the relatively newly developed programming language Swift that is loosely based off of Objective-C, an object oriented language. Swift was created solely for the purpose of programming in iOS (and OS X). The IDE used in development for Swift is Xcode, with its most glaring setback being that it requires a Mac to be run. Thus those with only a Windows or Linux desktop operating system are unable to venture into this field. Another large disadvantage is the requirement of a recurring fee of $99 a year to retain a publisher account, and even after submitting an application, must be tested before being officially released. While the testing phase works efficiently to keep the Apple App store regulated, it does not help the developer directly. [91]

Win 10

By developing an application in Windows 10 mobile, it is already completely compatible with a desktop running the Windows 10 operating system. This is a large advantage that Microsoft has over the competitors. Moving an application from Android or iOS to full desktop OS's is no easy task. This would require emulation at its simplest form or a complete code rewrite at its hardest. [92]

The Universal Windows Platform (UWP) is an architecture created by Microsoft for just that goal, creating universal applications to run on both mobile and desktop devices under Windows 10. These applications can be developed in C#, Visual Basic, C++, and even JavaScript, most often using the Visual Studio IDE. The IDE provides a template that allows the developer to create a universal project, regardless of targeted device. To release an app to the public the process is to first register as an app developer for Microsoft, a one-time $19 fee [93], determine pricing and package management, and submit the APK to the Windows Store. [90]

3.3.2 Wireless Communication Protocols

3.3.2.1 Bluetooth

Bluetooth networks are comprised of a master and slave system, whereby the master is able to send data to and request data from its slaves. To connect together there are several phases to follow:

1. Inquiry - In this phase, one module is 'introduced' to the next. This is often accomplished by setting a device into 'pairing' mode and allowing a mobile device to search and connect to the given address and / or name

2. Paging - This is the bridge phase which establishes the connection between Bluetooth devices.
3. Connection - The final and destination phase, it is at this point where the user is able to actively send and receive data. As well it can enter lower-power modes and wait for incoming commands. [94]

3.3.2.2 Wi-Fi

Wireless Fidelity is a wireless communication protocol, most notably allowing communication to and from the internet via a router. To keep a high-throughput, a system of encoding and decoding is utilized in 3 phases:

1. In phase 1, the data is digitized and encoded before being checked for errors. The correct frequency for transmission is then determined.
2. The data is then sent via a wave transmission.
3. Once data is received in the final phase, it is decoded, checked for errors once more, and able to be utilized. [95]
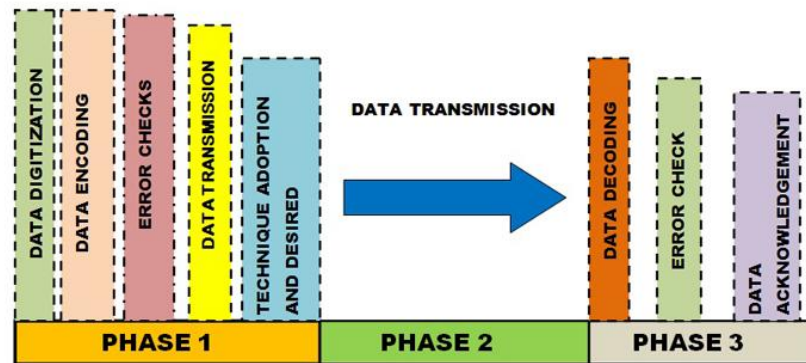
Figure 13. Wi-Fi Communication Phases (Permission Pending)

3.3.2.3 GSM Mobile Communication

GSM communication protocol is organized into 3 different layers:
1. Physical layer - The physical layer consists of the radio interface, which involves sending data to and from radio towers.
2. Data link layer - This layer denotes the connection between the network and mobile station.
3. Network layer - The third layer is comprised of Radio resource, mobility, and connection management. [96]

3.3.3 Programming Languages

The Automated Vehicle Anti-Theft Security Systems is comprised of several software components. These components include the microcontroller

programming, and the development of the phone application. Different programming languages can be used to create these two components.

Different programming languages are being taken into consideration. These languages can be used to create the software necessary to activate the cameras, record, store, send and delete video. The microcontroller used in this project is a big factor in choosing the programming language to develop the software because each microcontroller supports certain programming languages. Another factor in deciding which language to use, is the mobile Application platform. Apple supports Swift for their applications and Android supports Java.

3.3.3.1 Python

Python is an object-oriented, interpreted and high-level programming language [97]. Python can be used for software engineering, Internet Protocols, as well as operating systems interfaces. Python is very easy to read because of its clear syntax. Python code tends to also be shorter than other programming languages due to its high-level data types and dynamic typing [98]. The programmer does not have to waste time declaring the types of variables or arguments. This causes the code to be shorter and be developed at a faster time. Python has become a popular language in the Internet of Things. Platforms such as Raspberry Pi, one of the microcontrollers taken into consideration for our project, support this language [9]. Although this language is easy to read, write and compatible with Raspberry Pi, Python tends to run slower than other compiled languages such as C++ or Java [98] [99].

Python being an easy to read language gives the members of the team an opportunity to learn it in a quick manner. This factor is important due to the time constraint given and taking into account the time that has to be allotted to learning other technologies that comprise the system.

3.3.3.2 Java

Java is an object-oriented high-level programming language. Java can be used to create complete applications that may run on a single computer or be distributed among servers and clients. It can also be used to build a small application module or applet for use as part of a Web page [100]. Java just-in-time compilation is in many cases faster than interpretation [100]. Java is useful as well for developing applications in the Android Operating System. Android is one of the environments in which the development of the application is being considered. The use of java in mobile application development could be necessary if the platform is chosen to be on Android OS.

The two Computer Engineering members of the group have experience with this language. Java has been used as the designated programming language to be used for homework and projects in several undergraduate courses. This language facilitates the development of the Application because there is no need to spend time in learning the concepts and syntax on the language. That time could be spent in learning the mobile application development process.

3.3.3.3 C++

C++ is a middle-level programming language. It provides the low-level memory manipulation capabilities as well as the object-oriented programming. C++ is a compiled language. C++ also contains different compilers allowing it to run on many platforms, making it portable [101]. This language also supports an extensive amount of libraries. This enables the developers to complete projects in an easier and faster way. Nowadays, C++ has also taken part in the IoT era. Arduino microcontroller programming supports C++. This is one of the microcontrollers taken into consideration. This language can be crucial if the video processing is done using Arduino MCU.

In contrast to Java, some of the team members focusing on the software components of the project are not very familiar with C++. Time has to be allocated for the team members to familiarize with the language and be able to program the microcontroller successfully using this language.

3.3.3.4 C#

C# is an object oriented programming language created by Microsoft with the purpose of combining the computing power of C++ with the ease of Microsoft's Visual Basic. C# was mainly designed to work with the .NET Framework, which facilitates developers the exchange of information and services over the web and making the developers to create portable applications [102]. This language is based on C++ and Java making simple for Java and C++ programmers to learn it easily.

This programming language would be very useful for building the Security System application on the Windows 10 Phone. Furthermore, because this language is similar to C++ and Java, it would not take as much time for the developers to get familiarized with the language. Although, because not many UCF classes have taught or used C# for their projects, some planning and time has to be allocated in order to fully understand the capabilities and functionalities of C# and .NET framework to develop an application on Windows phone that can be user friendly yet able to integrate with the Automated Vehicle Anti-Theft Security System in order to perform the necessary modifications to keep the client's car safe.

3.3.3.5 Swift

Swift is a new programming language for iOS, macOS, watchOS, and tvOS applications that builds on the best of C and Objective-C, without the constraints of C compatibility [103]. Swift adopts safe programming patterns and adds modern features to make programming easier. Swift is backed by Cocoa and Cocoa Touch frameworks. Swift being a successor of C and Objective-C allows low-level programming such as operators, and flow control as well as object-oriented capabilities such as classes and generics [103].

This is a very new language created in 2014. Being a new language, the group members are not very familiar with this programming language compared to Java

which has been used in several undergraduate programming classes at the University of Central Florida.

3.3.4   Video Playback

Streaming video is content sent in compressed form over the Internet and displayed by the viewer in real time. With streaming video, a Web user does not have to wait to download a file to play it. Instead, the media is sent in a continuous stream of data and is played as it arrives. The user needs a *player*, a special program that decompresses and sends video data to the display and audio data to speakers [104].

There are several forms of video recording options for the Automated Vehicle Anti-Theft Security System. One of the options being considered is the owner of the system will receive a recorded video in wmv or, mp4 format and the user will be able to see it and play it back on the application. In this case, the cameras would record videos for a certain amount of time. After video duration is met. The video will be processed and sent to the application via the designated wireless communication method such as Wi-Fi, Bluetooth or GSM.

Streaming video is usually sent from prerecorded video files, but can be distributed as part of a live broadcast "feed." This is another option being taken into consideration for the display and transfer of the video. In a live broadcast, the video signal is converted into a compressed digital signal and transmitted from a special Web server that is able to in this case, send the same file to the user [104]. Once the camera is activated, the user will get a notification that will alert the user that camera was activated and the recorded has started. Once the user opens the application, he/she will be able to see the livestream. If the wireless communication between the microcontroller and application is Bluetooth it is not possible to live stream the video due to the limited bandwidth that Bluetooth has compared to Wi-Fi or GSM.

The streaming of video from one point to another can be done in several ways. After the video stream is compressed, the video shall be delivered from a streaming server to a client using a transport protocol. The two transport protocols that are being considered for our system are the HTTP Live Streaming Protocol and Real Time Transport protocol.

3.3.4.1 HTTP Live Streaming Protocol (HLS)

HTTP Live Streaming Protocol, also known as HLS, is a HTTP-based media streaming communications protocol created by Apple that enables users to send live or prerecorded audio and video from any web server to any device. HLS is a TCP based protocol which was designed for reliable delivery rather than a steady flow. HLS consists of three components: server, distribution, and client software. The server component is in charge of taking the input streams received from the recording device and encoding them in a suitable format ready to be delivered. Within the server component, the media encoder takes the signal from video device, encodes in a format such as H.264 and encapsulates video the signal in

order to be transported [105]. The encoded media is then sent in the MPEG-2 Transport Stream to the Stream Segmenter as seen in Figure 3b. The Stream goes to read the Transport stream from the local network ad divides it into smaller media files with an index file that keeps track and references of the individual media files. After this process, the media files are ready to be delivered [105]. The Distribution component is a web server that is in charge of delivering the media and index files to the client over HTTP. Lastly, the client component begins fetching the index file, based on a URL identifying the stream. The index file then specifies the location of the available media files, decryption keys, and any alternate streams available. For the selected stream, the client downloads each available media file in sequence. Each file contains a consecutive segment of the stream. Once it has a sufficient amount of data downloaded, the client begins reassembling and presenting the stream to the user [105]. During ongoing broadcasts, the client loads a new version of the index file periodically. The client software looks for new media files and encryption keys in the updated index and adds these URLs to its queue this way the stream could get updated and be reassembled successfully. Figure 3b below shows the process of HTTP live streaming video to a client.
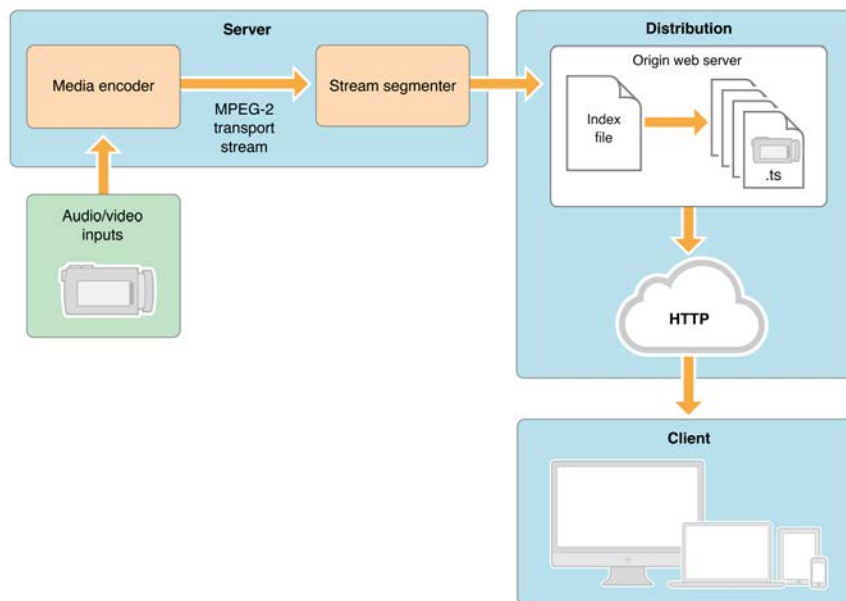

Figure 14: Figure3b: Video HTTP Live Streaming. Permission pending from Apple

This protocol is supported by iOS devices and Android devices. This protocol is a crucial part for the development of our Mobile application and enabling the video streaming from the MCU to the user's mobile application especially when the platforms considered for the application such as iOS and Android also support HLS.

3.3.4.2 Real Time Transport Protocol

The Real Time Transport Protocol is a transport protocol built on UDP and designed specifically for real-time transfers. It's closely associated with the Real Time Control Protocol (RTCP), which operates at the session layer. The primary function of RTCP is "to provide feedback on the quality of the data distribution," allowing actions such as adjusting the data rate. Another protocol that works with RTP is Real Time Streaming Protocol (RTSP). This is a presentation-layer protocol that is described as a "network remote control." It resembles HTTP in some ways, and it carries requests to initiate activities such as playing, pausing, and recording [106].

RTP, RTCP, and RTSP all operate on different ports. An RTP session may contain multiple streams to be combined at the receiver's end. RTP is used by standalone players such as RealPlayer, Windows Media Player, and QuickTime Player [106].

Both protocols described above are supported by the desired platforms of out mobile application. In our system, video is being passed across the internet and has to get to the user in a reliable way. HLS is able to do that in a better way than RTP because HLS is able to run on TCP which focuses on security and reliability. RTP being based on UDP is very useful in other cases such as games when speed is very important and there is constant communication between the client and server.

4.0 Realistic Design Constraints

4.1 Relevant Standards

In this project we made sure to be aware of relevant standards that may affect the product quality and / or reliability. Listed below are our standards that we used throughout the design and development process.

- CSI-2 - This serial bus provides interfacing between a camera module and its associated microcontroller. It defines its data bus lines, image format, bandwidth, and number of channels. [107]
- MPI – The Message Passing Interface standard defines the message passing and procedures for use with parallel-processing routines protocols. [108]
- IEC 61739 – The IEC 61739 is a standard dealing with Photovoltaic Modules safety. It ensures that every photovoltaic device, like solar panels, are to be made safe against electric shock hazards, and fire hazards. This includes the mechanical and structural safety. The standard is divided into 2 parts, the requirement for construction and the requirement for testing. In order to pass, modules must have no visual defects and a power output degradation of no more than 5%.
- BLE – Bluetooth low energy was created with small embedded devices in mind, with a focus on as the name suggests, low energy costs. It's helpful for projects like this that hold very stringent power requirements.
- SD Association SDHC Standard – SD cards that are between the range of >2GB – 32GB must have a FAT32 file system.
- ISO/IEC 14766:1997 – Provides guidelines for telecommunications to allow OSI upper layers to operate on the Transmission Control Protocol without knowing that it is operating on the Transmission Control Protocol Internetwork [109].

4.2 Economic and Time Constraints

An economic constraint is a restriction to a certain project by financial means. The economic limitation on our project is monetary. As discussed in the budget and finance section, at the beginning of this paper, this project is not being funded by any third party organization or company. This is being funded by each of the individual members participating in the project. Many of the design decisions will be based on cost of the parts needed to make the design. A detailed list containing all the parts used to complete this project is going to provide us the total cost that needs to be split equally in order pay for the project.

Due to the monetary constraint, our Research and Development stage is limited compared to other commercial car security systems. Extensive research and analysis has to be made in order to pick and acquire the different components that comprise the system. Buying different models of the same component to test their functionality and operability is not a viable option due to budget issues. In the case

of a component not being compatible or getting damaged in the development and integration stage, a new component will be acquired and the budget would be allocated for that part. The economic constraint has been recognized and a budget was planned accordingly to overcome this constraint. The budget and list of hardware components that will be used to create this project can be found in the Estimate of Budget Section.

Another constraint in the development of products is time. All projects are given a deadline in which they need to be completed and functional. The types of time constraints that must be considered for our project is found within the class ending time and correlating schedules between team members. The Automated Vehicle Anti-Theft Security System must be completed within two semesters. The first semester, Senior Design 1, mostly consists of team meetings for brainstorming, and researching both software and hardware components that are needed for the development of the system. The project must be completed from design to final product by the end of Senior Design 2. Each semester is 16 weeks which gives us 16 weeks to create the final product after the research stage is done and the parts for the system are acquired.

The technologies that are used in this project are not something that we were already well-versed in before starting. There is a period for learning the technologies are necessary to implement a system with the requirements that we desire. Learning about these technologies and parts as well as learning the implementation and integration is time consuming and has to be planned accordingly in order to leave time for the actual implementation. The setting of milestones as well as weekly meetings for updates will help us stay on track. The milestones section discusses into further details the sections of research, planning, development, testing and delivery of the final product.

Our team consists of students of different degree types. Each member has different work, class and personal schedules. The time constraint of completion before the end of Senior Design 2 will be incorporated into the different schedules in order to meet the final deadline of the product. Excellent communication and time management skills are needed to overcome this constraint. As mentioned before the creation of milestones will help achieve this goal. These milestones can be seen in its respective section.

4.3 Environmental, Social, and Political Constraints

Environmental

The environmental constraints' objective within the scope of our project are to make sure that any and all harmful effects on the environment are avoided. This applies not only to our design, implementation, and testing phases, but also to the potential mass production phases of a future related product. Specifically, with respect to the use of solar cells and their life cycle, there shall be outlined a procedure in which to dispose of the solar panels and their associated spent components with no adverse effects to the surrounding environment and fauna.

Social

As we pursue the goals and specifications outlined in this project, we will follow constraints with respect to respecting appropriate social and interpersonal levels. Due to the nature of a security system, there may be the potential of tense and extreme situations that must be handled in a controlled manner. Within the realm of theft and vehicle accidents, filming of the surrounding pedestrians and drivers can serve to agitate and provoke negative action. That is a core reason to make attempts to keep our security device less obvious to outside view. As this is a goal, we must also keep in mind the prototype nature of this project and the phases of development. The form factor will take a lower priority in comparison to overall function of the system.

Political

As the developers of this project we must follow lawful standards in the United States. In the best interest of the project and future sustainability, we will make an effort to follow the standards that our device will most often follow under the jurisdiction of. For example, following popular Florida traffic laws that are also present in California and Texas, and not necessarily one obscure text in a small Montana city. Two things to keep in mind specifically in the case of dash cam products are the legality concerns of having an obstructed view, and performing electronic surveillance. With respect to his project, the entire device will be placed above the car atop the roof, unlike common dash cams which are displayed somewhere on the internal of the front windshield glass. Due to this, the driver will never even see the system much less have their view obstructed by it. With respect to surveillance of the public in the United States there are no federal laws against existing dash cams. However, there are laws that reside over audio recording which can effect many situations with common cams. Our system however does not use any sort of audio input from the security system, only from the user's mobile device. The only point in which there would be a conflict of legality regarding audio recording, that issue would persist whether or not the security system was in place.

4.4 Ethical, Health, and Safety Constraints

Ethical

Ethical constraints consist of constraints on a product that go against social ethics. For our project, we are making sure we use materials that are considered safe. We will not cut corners and buy cheaper, but toxic materials that are potentially harmful. The product will work as advertised, as a functioning security system. We will make sure that the design is made to the specifications we set, and not undercut to provide a profit. Our project is also for non-profit, and is being done to show and test the skills we learned throughout our time at the University. One ethical concern our project can bring up is that of public filming. However, according to the First Amendment, which protects free speech, public filming under US law is not illegal as long as it is done in public areas and not done to purposely expose someone's private details. For our project, the video cameras would only be recording when someone comes close to the owner's personal car and wouldn't

be recording the approaching person in a private situation. Our project is intended to be used on top of cars to film only when the owner's security is in possible danger. [110]

Health and Safety

Health and Safety constraints are those constraints on a product that could affect the safety and health of others. For our product, we will make sure that all products bought are shown to have been tested to work without fault. Our product will utilize solar energy to power it. All of the solar panels used will have been made to the IEC 61739 standard for Photovoltaic modules. This standard was put into effect in order to put standards on the quality of Photovoltaic modules, protecting against possible shock, fire, and structural hazards. This product is not a product intended for children. We will make sure that all of our wiring and electronics are spaced appropriately according to standards in order to prevent possible fire from malfunctions or overheating. As stated earlier, we will make sure to use all non-toxic materials in the building of our product. Our product will be within reasonable weight limits for being mounted to the tops of vehicles. We will also make sure it is secure enough that the product doesn't pose a hazard to drivers when the vehicle is in motion. Our hope for this project is to raise the safety of those around it. [111]

4.5 Manufacturability and Sustainability Constraints

There are also manufacturing and sustainability constraints that will be accounted for. For manufacturability, we will talk about the availability of key components, special tools needed to create the design, flexibility of the design to adapt to alternative more efficient/economical components and whether the design requires high accuracy when being built. Sustainability in this case is interpreted to be how long our design can last before be considered unusable anymore, whether or not the resources used are able to be used indefinitely, the reliability of the design and the general life span of the design.

The manufacturability of this design is relatively straight forward. Almost all components used will be component already on the market that are readily available. For example, the Raspberry Pi module that will be used are very popular type of high end microcontroller so there will be no short supply from this. One of the components that can make this system unique is the chassis. This is important because this could call for new types of manufacturing design in order to produce many chassis. Also, once all the components are secured onto the chassis, sealant will have to be added to ensure water resistance. This is a manual process which may take time and some testing to ensure proper function of the design in watery conditions. The design will use universal components in such a way that if any specific component becomes unavailable, multiple similar alternatives will be able to replace that specific component without sacrificing performance and operation. In terms of finding more economical products, special attention will need to be shown on choosing the right batteries as they can become very temperature sensitive and so cheaper batteries could result in destruction of the batteries. The

design will only need a chassis that can mount to the roof of a car securely and so must have high accuracy when being built in terms of making sure the design acts as one piece and is not loose at any point. Inside the chassis each component will need to be securely attached to prevent loose components from hitting other components when the car is in motion thus damaging the entire apparatus. The design needs to be structurally sound when being built in such a way that it will take testing during manufacturing to ensure quality. Other than the overall structure, each component will be easy to secure in its place and minimal wiring will be required.

To start the sustainability portion, our system is completely solar powered so it will not need external sources of energy and will be readily available to work and harvest energy as long as the sun lasts which is indefinitely. Because of this independent power supplying method, this cuts out major concerns that most designs might have with energy resources and consumption. However, the major limiting components in our design will be the batteries and the solar panels. As explained in the solar panel research section, most solar panels tend to lose their efficiency rating after several years and tend to lose their ratings even faster when staying exposed to hot or freezing temperatures. However, these losses are almost negligible with only a loss of about 0.8% lost per year of their previous efficiency [112]. Batteries will have short lifetime than solar panels and last anywhere from 500-1000 charging cycles depending on their depth of discharge [113] & [20]. The main concerns for life span are whether the system can continuously store and harvest enough energy for several years. Even if the batteries are not being used, they typically last only a few years. The estimated life time from this is 10-25 years without the loss of any vital part of the design and if the batteries are replaced every 1-2 years. If certain budget expectations are meet, the system could be sustainable as a business.

Our design will be reliably because it will not need external resources to operate other than the sun. Since cars can be parked in the sunlight and driven in the sunlight, enough energy should be created to let the design last several hours without needing recharge. The design will also have all internal components securely fastened and have a hardened chassis in order to be durable in extreme conditions so the components do not get destroyed. An extreme condition includes: strong winds up to 80+ mph winds because the car will be assumed to be driven on highways.

5.0 Project Hardware and Software Design Details

5.1 Initial Design

5.1.1 Block Diagram

Below is the initial design of the project and the modules and interfaces involved. As well, the color-coordinated blocks show which group member holds primary responsibility of their completion. Note that the two blocks Raspberry Pi Cluster and Android Application have shared color gradients. This is to distinguish the shared action, as the Raspberry Pi Cluster is developed primarily by Sean and Ben, and the Android Application by Gerardo and Ben. What is also important to note is that these roles are not restrictions placed on members, as each module will have every members' contribution in varying amounts.
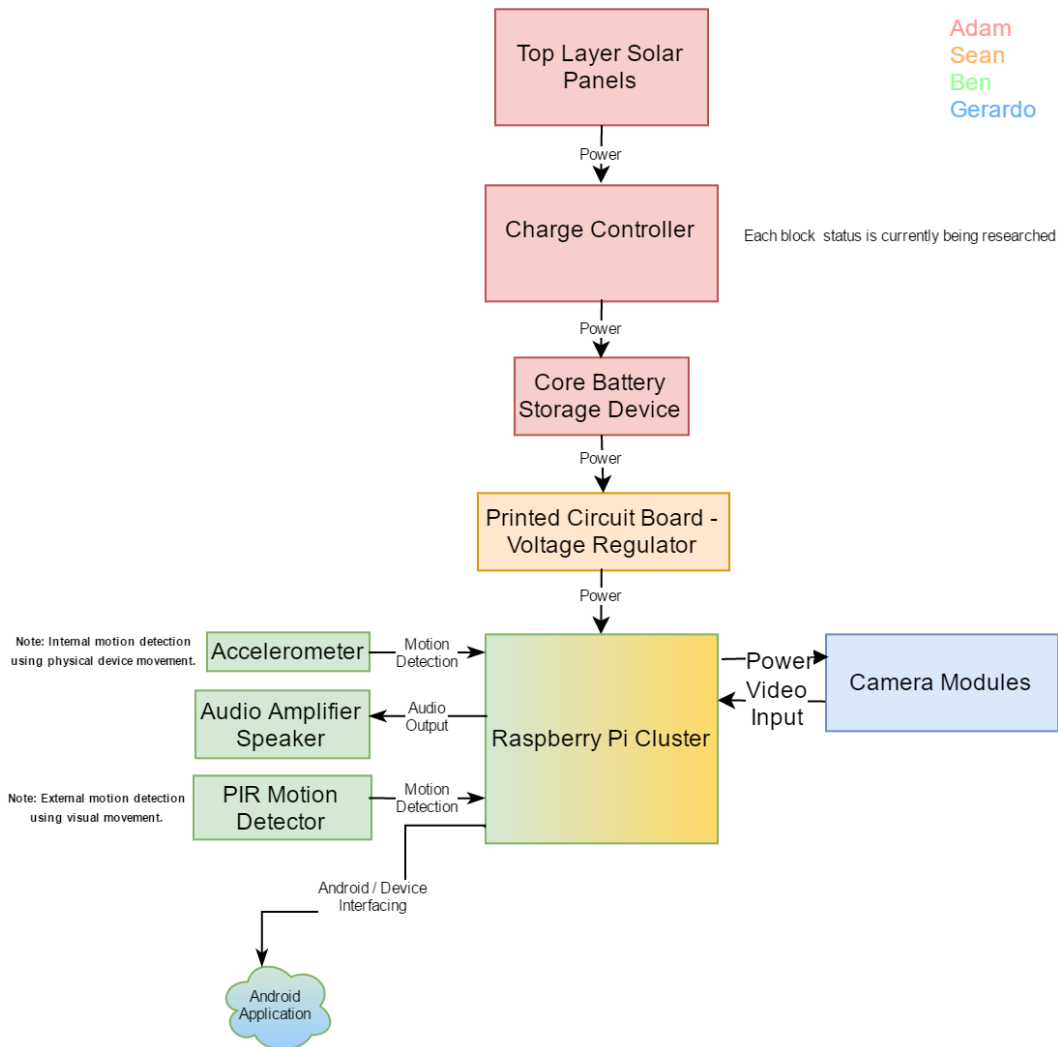
Figure 15. System Modules and Interfaces

The Raspberry Pi Cluster is displayed in greater detail in the figure below. Each Raspberry Pi is connected via an Ethernet switch, while the head node will initiate the internet connection via the GSM dongle. Additionally, each Raspberry Pi will be connected to their individual storage device which will store their Operating System, Raspbian, as well as the video data stored from their own respective camera module. Using this setup, the system will have enough processing power to handle the video input as well as the overhead system processing such as mobile communication.
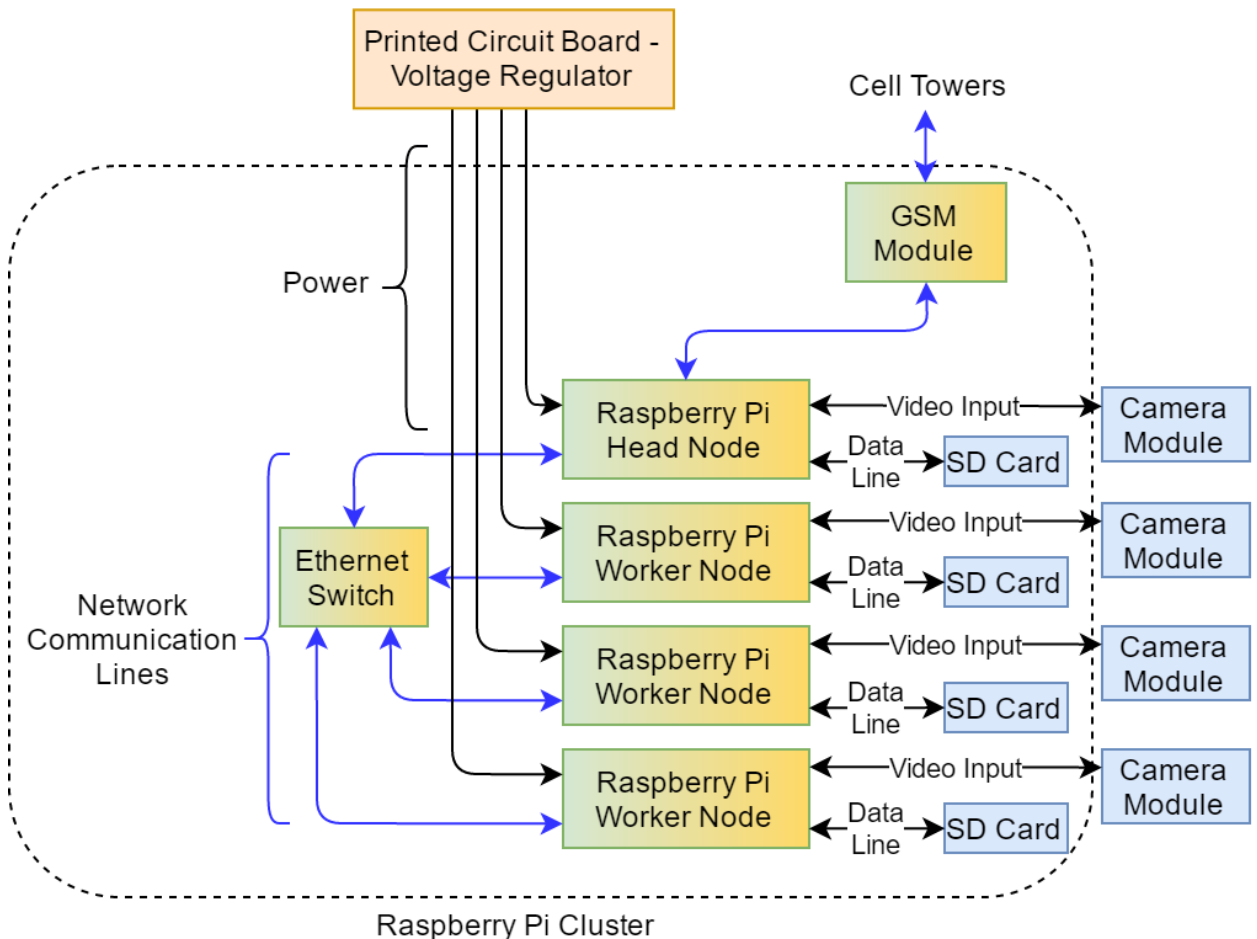
Figure 16. Raspberry Pi Cluster Modules

5.1.2 Android Application

In the figure below, shown is the initial class diagram devised to handle the Android application.
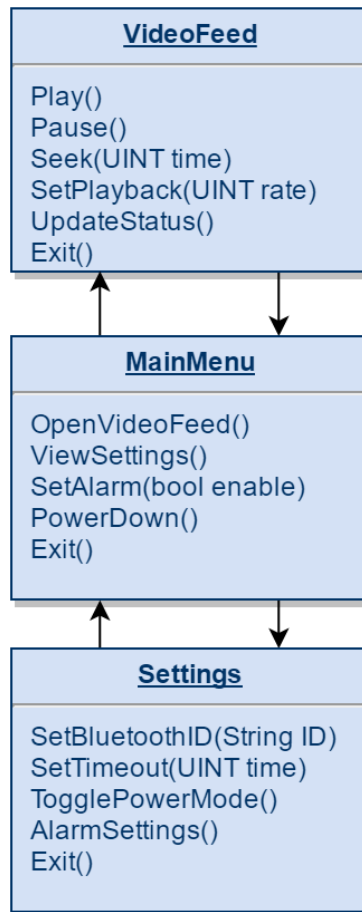
Figure 17. Initial Class Diagram

From the main menu, we will be able to view the video feed which contains playback settings for the camera input, set the alarm for the device, power down and enter the settings menu. As we progress in development we may streamline the user interface as well as add functionality that arises out of need. Our purpose of the application is to allow the user full access to their devices capabilities and to customize its uses to their personal style and taste.

5.2 Microcontroller

A microcontroller is essentially the "brain" of our project. The microcontroller is in charge of communicating between all of the separate devices. It is also the source of where our commands will be given. Each part of our project that has a function will be given the function through code that is processed with our microcontroller. When searching for a microcontroller, we wanted to make sure that it had all of the properties and the specifications needed in order to run a project as ours. The main factors we had to consider were the amount of cameras being used, amount of sensors needed, low-power consumption, and ability to communicate wirelessly to other devices if needed. We needed a microcontroller that was powerful enough to do all of this. We decided to go with the Raspberry Pi 3 Model B. The specifications are shown below:

The Raspberry Pi 3 was chosen after much consideration. We carefully looked over each microcontroller and weighed the advantages and disadvantages of each. In the end we decided on the Pi for several reasons. The main reasons are given below:

- Price - The price is at a low $35 which is an incredibly low price for the amount of usability the controller gives. Some of the other controller's we looked at were cheaper, including the Arduino UNO. However, the UNO didn't provide as much utility as the Pi.

- Size - The device is super compact, at a size of only 85.6 mm x 56mm x 21mm, which gives us flexibility when designing our chassis. Coming at such a small size means it also weighs at an almost negligible 45 grams. Most microcontroller are small like the Raspberry Pi, but the Raspberry Pi was the smallest, lightest weight microcontroller with the most utility

- Wireless Capabilities - The Raspberry Pi was one of the only microcontrollers we were looking at that came with built-in wireless capabilities. The Pi comes with both a Wi-fi 802.11n and a Bluetooth 4.0 wireless communicator. For our project this was almost essential. With all the other microcontrollers, we would have had to buy adaptors in order to get the microcontrollers to talk wirelessly. Since our project consists of the cameras feeding video wirelessly to a user's mobile device, the wireless communication is essential. The Raspberry Pi makes it much easier and reliable

- Storage – The Raspberry Pi comes with the ability to add-on an extra MicroSD storage card onto it. Most, if not all, of the other devices we looked at had very small built-in memories, most being flash memory. The reason storage is so important to our project is for the video feed. Video takes up a lot of memory, especially if it is being fed consistently through four cameras. The MicroSD allows us to buy bigger storage in order to fit our needs and also doesn't add much weight or size onto our overall build.

- Output Ports – The Raspberry Pi has a bunch of different output ports available for use. It comes with an outstanding four USB ports, which when compared to other microcontrollers which at most had one. The USB ports are very important since many peripherals like to use USB ports. Having four allows us the freedom to search for all sorts of peripherals without being limited by connector types. The pi also comes with a video output and an audio output. These are HMDI/Composite and HDMI/Headphone respectively. The video output port isn't very essential to our project, however, the audio port is. All of the other microcontrollers we looked at didn't come with any sort of audio or video output port. Part of our specifications and requirements include an audio alert given once a user prompts to. With a built-in audio jack, we are able to cut-down on costs of buying an adaptor, and are able to easily communicate between the speakers and the controller. One thing to note about the audio output port is the low-power it gives. The Raspberry Pi's audio port has very a low current supply, which can limit the sound or type of speakers we were to

choose. However, since the Raspberry Pi comes with an abundance of USB ports, if a speaker is found using USB to power it, it can be easily integrated with our system without losing volume.

- Processing – The Raspberry Pi's crowning jewel is it's processing power. Unlike most other microcontroller being able to process instructions up to 16-bit, and the usual more powerful being able to process up to 32-bit instructions, the Raspberry Pi can process up to 64-bit instructions. For basic designs, a 16-bit microcontroller should be able to get the job done, however, for things like processing the IMU detection and sending video feed wirelessly, having a higher bit system is ideal. The other big component of the Raspberry Pi is its processor, or CPU, which has an insane clock rate of 1.2 GHz. The second highest clock rate of the microcontroller we looked at was the ATSAM3N00A which had a clock rate of 48 MHz. This very fast clock rate is essential for our project. Since we have four cameras being fed to the same device, a lot of processing will be happening. With all of the other microcontrollers, there may have been an issue when trying to process that many different feeds at once. Either it would be too slow and information could be lost, or the worst could be it overheating and ruining everything. Not only does the Raspberry Pi have a good clock rate, but it has a good memory at 1 GB RAM. RAM is essential when trying to process a bunch of things at once. All of the other devices we looked at had smaller RAM sizes, with the Mega coming in second at only 8 kB of RAM. The last processing unit it came with is a video card. The GPU has a clock rate of 400 MHz which is pretty impressive, however, for our project we won't really be using the GPU. This is due to our only display being that on the mobile devices.

Power

For our design, we want to make sure that our device uses as little power as it can. Like most of the other microcontrollers on the list, the Raspberry Pi has an operating voltage of 5V. However, this operating voltage is a recommended operating voltage, with the Pi being able to run as low as 3.3V. Many of the microcontrollers we looked at also had operating voltages of around 5V with the same variance of around 1.8-3.3V minimum. Unlike the other microcontroller's however, the Raspberry Pi is very sensitive with its' operating voltage. It isn't recommended that it be used at any lower than 5V. Since the Raspberry Pi is very finicky with its' operating voltage, this can pose a problem. The Pi has a lot of components to it, causing for a longer, more drawn out booting process. If the voltage or current drops a little too far from recommended, the Pi is very likely to corrupt much of the data stored onto it, and possibly could damage the entire unit. Another possible issue with the Pi is the current that is drawn. The Pi has a particular amount of current needed to run and also has limits to how much current can be drawn from its' several USB ports and GPIO pins. Below is a table outlining the different power consumptions:

	Average	Maximum
Recommended PSU Current Capacity	2.1 A	2.5 A
USB Current Draw	600 mA	1.2 A
GPIO Pins	50 mA 16mA per pin	50 mA 16 mA per pin
Camera Module	250 mA	250 mA
Booting*	350 mA	750 mA
Idle*	300 mA	300 mA
Video Playback*	330 mA	550 mA
Stress*	850 mA	1.34 A

*Raspberry Pi only connected with HDMI, Keyboard, and Mouse [114].

Table 7. Current Draw Comparison [49]

This information is very important to note when setting up our PCB. Since the microcontroller is known to have issues if the power given isn't just right, we are going to be regulating the voltage and current coming from the battery and feeding into the controller. Our biggest issue is making sure that the current is regulated properly and can give at least 2.1A. Since our project also consists of many different peripherals, we want to be sure that all of our peripherals can be properly powered by the Pi itself. To make sure of this, we used the table above when picking devices to make sure the devices don't need a power supply exceeding the amount that's able to be provided through the Pi itself.
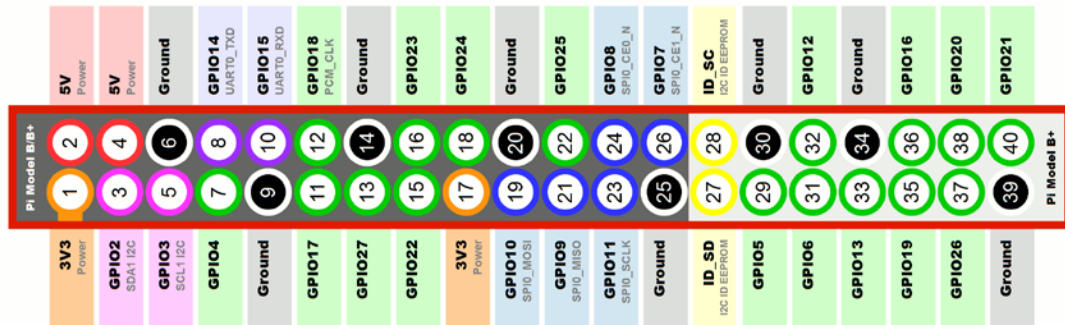
Figure 18. GPIO Pins (Reprinted with permission from Raspberrypi-Spy)

Peripherals

The Raspberry Pi also comes with an impressive 40 GPIO shown above. We won't be using nearly close to all of these. Our design will be utilizing two of the 5V pins in order to power both the PIR sensor and the IMU board. These will also both utilize a Digital Input pin in order to communicate with the board once the appropriate flags have been triggered by the respective sensors. The camera we will be using will be connected via the camera module. Both the PIR sensor and the IMU have low power consumption, the PIR being passive, allowing for the perfect use on the GPIO pins. The speakers utilize the audio port and the USB

ports. Having extra GPIO to work with is always an advantage since some might stop working, or if we decide to add more parts we have the flexibility to do so.

The Raspberry Pi 3 Model B was our perfect choice for a microcontroller when relating to our project. Not only does it have the power and speed needed to keep up with the heavy demand put on through all of the camera feeds, but it also is lightweight, small, affordable, and full of utility. The only problem is that each Raspberry Pi only has the capability of powering one camera module at once. It also starts becoming slower and unreliable the more peripherals added to it. Since we need to utilize several cameras for our project, we thought of buying a splitter which will allow us to split the camera module port into four more ports for use. However, the problem we faced with this was still whether or not a single Pi had enough power and even processing speed to run more than two cameras efficiently. We decided that it didn't. So instead we decided on buying four Raspberry Pi. This way, each Raspberry Pi will be able to solely focus on one camera each. This saves the possibility of issues coming up and also opens up even more processing power for us. In order to get all of these Raspberry Pi to work with one another, the must be set-up in a cluster. This cluster essentially connects all of the Raspberry Pi together onto one network and work congruently with each other. With this, all four Raspberry Pi can act as if they were one very powerful Raspberry Pi. More about this design is in detail later.

5.3 Raspberry Pi Cluster

For our project, our Raspberry Pi Cluster will be constructed using the following:

- Four Raspberry Pi 3 Model B microcontrollers
- 4 Micro SD Cards
- 4 Camera Modules
- Ethernet switch
- GSM Module

A key difference between the most common Pi clusters and this projects is the absence of a USB hub to supply power to each Pi. For this project we will utilize the Printed Circuit Board as a voltage regulator discussed further in this paper.

The GSM module connected to the head, or master, node will supply the internet connection in which we would interface with the mobile Android application. The head node would then be connected to an Ethernet switch and every other node would in term be connected to the switch to provide a complete internal network. Each would node would also have the following connections; Micro SD storage device, Camera Module via a CSI ribbon connection, and power input via the PCB voltage regulator. With this setup the device as a whole would have the capabilities to communicate internally between nodes, receive steady power input in each node, and handle the processing power necessary to support 4 simultaneous CSI camera modules.

Node Communication

The local network between each of the nodes will be sustained by the master node connected to the Ethernet switch which would further disperse the connection to each node. To accomplish this, we'll be using the MIPCH investigated in the prior research section.

5.4 Power Storage

For our design, we decided to go with a 12-volt battery with a 10 amp hour capacity that would be connected to a 18 volt 100 watt solar panel through a charge controller. The load, which consists of the Raspberry Pi modules will be connected to the charge controller as well. However, the Raspberry Pi operates at 5 volts so we will put a linear regulator in between the charge controller and the load [115]. The linear regulator will be used as our PCB design and after doing research, it was found that there are no linear regulators that can convert 12 volts to 5 volts at higher currents than 6 amps that would fit our design. So instead we will put 4 linear regulators connected to the load and then one goes to each Raspberry Pi module. We looked up schematics to build that can hold 3 amps at a time which is what we need because the Raspberry Pi might pull up to 2.5 amps each. Here is diagram of the general layout of the power system for our design:
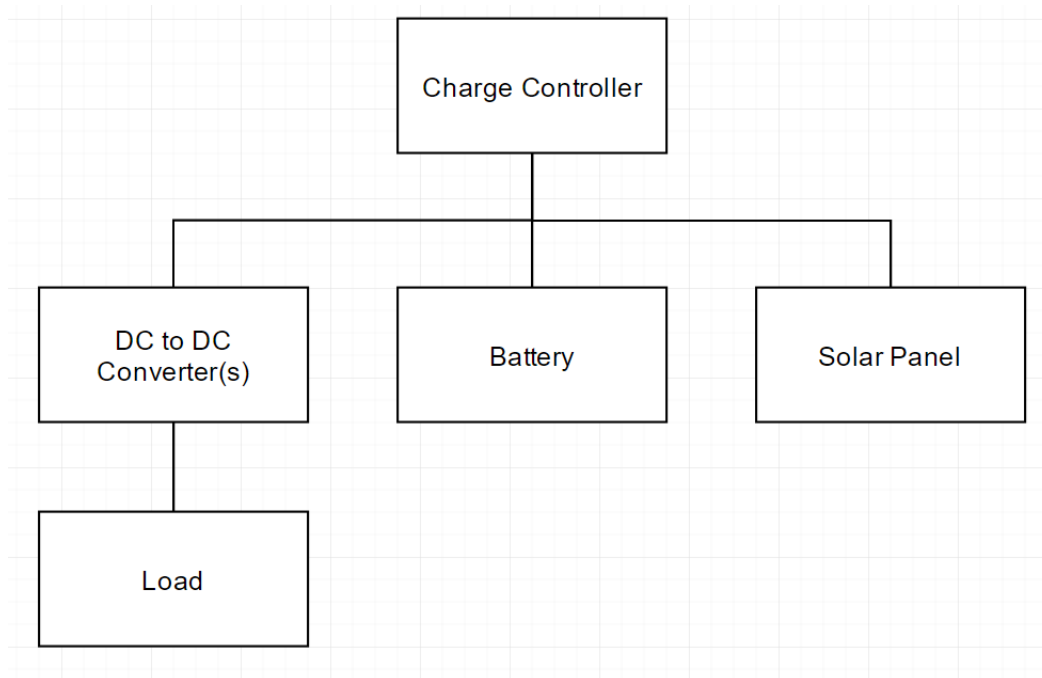
Figure 19. Diagram of Solar Charging System made at www.draw.io [116]

5.4.1 Solar Panels

As explained in the research section, it was explained that we will need a charge controller to connect the solar panel and battery pack and load together. Since our design is small enough to consume most likely less than 100 watts and closer to 25 watts at any given time, we will not need very much energy from the solar panels during a certain time. Given this, we should be able to produce enough needed

power to not only operate the design but also to store excess power simultaneously. We will assume the top of the car to be 2.5 feet wide and 4 feet long. If this is the case, we can assume the Suaoki 100W 18V 12V Solar Panel Charger SunPower Cell will be small enough to fit the contour of the car [117]. Next we will explain the reason and math behind choosing a 100 watt 18-volt solar panel.

For our project, our design is planned to be running multiple Raspberry Pi modules at once that will detect motion with both motion detection devices. The modules will be using consuming a low amount of power as they will only be on to process information from the sensors and will determine whether other devices needed to be turned on if there is a threat nearby. These Raspberry Pi modules will probably be using around 1 watt each at these low energy states because not many ports will be in use and minimal processing will be required [118]. However, we will assume they are using much more power so we don't underestimate the power consumption of our design and have a failure later on, we will assume they are each running at 0.9 A of current at 5 volts and we will be using 4 modules. The total power consumption was estimated using the following equations where the V = 5 volts, I is the assumed 0.9 amp current consumption and P is the power each Raspberry Pi will need to operate effectively and continuously. After the power of one Raspberry Pi was found, the total power consumption was found with the symbol P_{tot} [119]:

$$P = VI \qquad \textit{Equation 3}$$

$$P_{tot} = 4P \qquad \textit{Equation 4}$$

All of these equations are referenced. This assumption is about 3 times the average power consumption when a Raspberry Pi module is shooting 1080 resolution video without saving it [115]. This assumption will be used to make up for the minutes each day where the design is in full power mode using more power for the cameras, the speaker and cellular module. We will assume they will be operating at maximum power each which will be assumed to be the maximum power station unit rating: 5 volts at 2.5 amps. This gives 50 watts for the entire system needed if each Raspberry Pi module is running on highest power consumption using the previous formulas for power to find P_{tot}. If we assume there is a threat once a day for 5 minutes, this would trigger the cameras to turn as well as other accessories thus turning into full power mode. Next, the following equation was used to calculate the watthours needed for this full power mode where wh is watthours and T is the time in hours this full power mode will be on [119]:

$$wh = PT \qquad \textit{Equation 5}$$

The time is 5 minutes, so plugging P = 50 watts and T = 5/60 gives 4.17 watthours. But there is uncertainty on how many threats can occur and how much motion will be detected to trigger the entire system to turn on, so we will make sure our system can last under any circumstance so there is enough power to record by using higher rated batteries; so the high power where the current is assumed to be 0.9 amps for each Raspberry Pi is necessary to include times when the system is in

full power mode. Using this assumption our total power needed will be 18 watts at all times according to the power equations when the current is 0.9 amps. Using the Raspberry Pi module, a SD card with an operating system was loaded onto the module and was processing operating system while having accessories attached. The power consumption was measured at different times and is shown in the graph below. The average, highest and lowest values measured for power consumption were recorded for 4 different events using an TS-836A Plug Power Meter which measures the power from an AC wall outlet [120]. The first test is just turning the Raspberry Pi on with the operating system loaded on the SD card which is labeled as "Base OS" in the graph below. The second test called is when the camera was attached and powered on labeled as "Camera On." The third state was when different built in applications were being loaded on the operating system labeled as "Processor Testing." The last test was when there were many accessories being used via USB like: keyboard, mouse and camera simultaneously. This last test was labeled as "Multiple Accessories," as shown in the graph below:
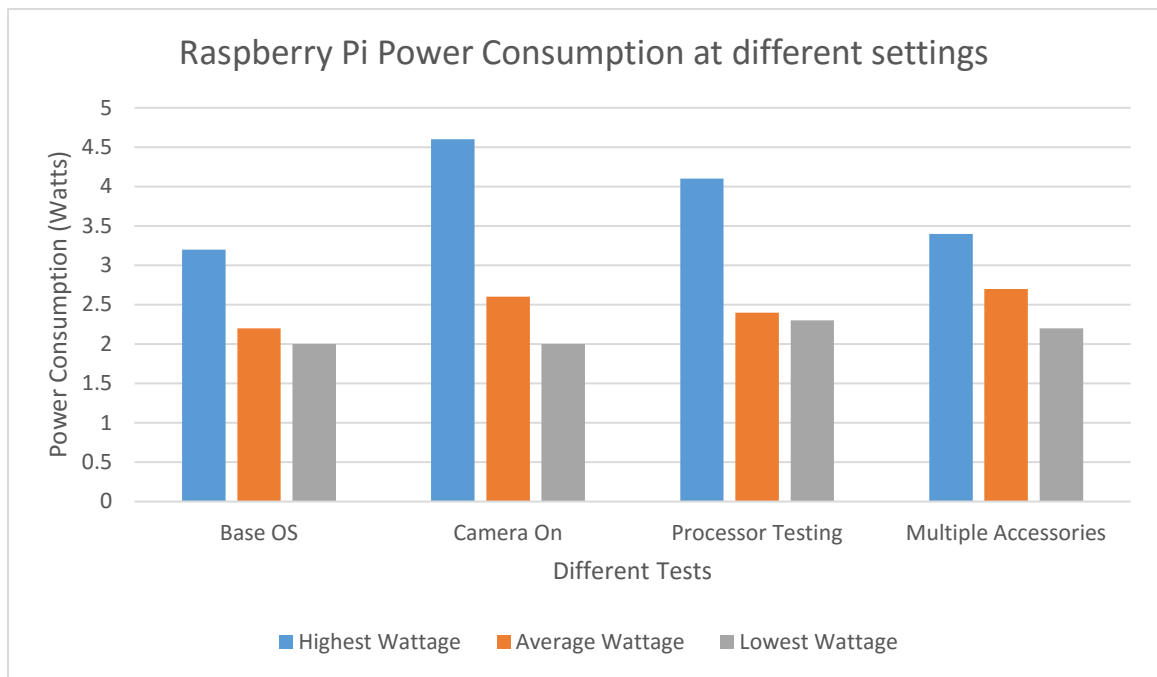
Figure 20 of Average Power Consumption during Different Tests on a Raspberry Pi module

From the above graph, good estimates can be made for the average overall power consumption one Raspberry Pi model will need and the maximum it might need at specific times. As shown by the orange bar in the above graph, the average power consumption was about 2.5 watts. This gives a total average power consumption of about of 10 watts, but it is still uncertain if the Raspberry Pi module will need a lot more power once the everything is loaded onto them with each accessory working. Also, the wattage spikes show potential for large amounts of power consumption at a time. On top of all of this, we may be using a small switch to cluster the Raspberry Pi modules together which would require an extra 5 volts of power which would take up to 0.6 amps [121]. Given all of these requirements, the

current assumption of 18 watts of average power needed is reasonable and will be used going forward.

Using a battery calculator which was found when doing research, it was found that the required solar panel will need to supply 96 watts if we assume get 4.5 hours of direct sunlight hitting the solar panels each day which [122]. This sunlight assumption is based on the average amount of sunlight received in the southeast portion of the United States [123]. Because the design will be on top of a car, we will assume the top of the car will always be facing directly upwards because driving conditions are mainly on flat land, so this will maximize the amount of sun that directly hits the solar panels. Given That we made rather conservative assumptions on power usage, the 96 watt solar panel is probably a very good estimate for our design to ensure we always have enough energy being harvested. This 96 watt number was found using the following steps, we first look at the following formula where P_{tot} was already found to be 18 watts, T_{on} is the amount of time the design will be powered on each day and whd is the watthour usage per day needed to supply the design each day. T_{on} would normally be 24 hours because the design is supposed to always be on to detect incoming motion so here is the equation [119]:

$$whd = P_{tot} * T_{on} \qquad Equation\ 6$$

The watthour usage per day is then found to be 432 watthours. If we divide this number by the assumed 4.5 hours of direct sunlight each day, as shown the equation below, we will get the necessary wattage for our solar panel [119]:

$$\frac{whd}{(hours\ of\ sunlight\ each\ day)} = P_{solar} \qquad Equation\ 7$$

this gives the 96 watt value needed from our solar panel, since most solar panels come in 50 watts or 100 watts arrays, we will round up and look for a 100 watt solar panel. As stated, this panel can produce 100 watts of power when placed in direct sunlight which is more than enough for our initial power consumption plans.

It was decided to use an 18-volt solar panel because this is one of the most widely available voltage ratings on the market for 100 watt solar panels. After looking at solar panels with good reviews, it was found that the: Suaoki 100W 18V 12V Solar Panel Charger SunPower Cell is good choice [117]. A benefit of using this exact model which could be crucial, is that it can flex and adapt to the contour of the car or our chassis contour. This will be good so the design looks more professional and allows to gather more energy from the sun when the sun is at different angles instead of just when the sun is directly upwards. Once the solar panel was bought, it was found to be very flexible and can easily bend to the shape of the top of a car, it was also very thin and was able to fit comfortably on top of a 4 door sedan car without any edges sticking out. Next, using a multimeter, the amperage and current was measured across the two terminals of the solar panel and the results were measured.

5.4.2 Charge Controller

To start, we will plan on buying a pulse width modulator once we decide on an exact solar panel to buy. We will start with a pulse width modulator charge controller because it is the economic choice and can do the job properly even though it is not as efficient as MPPT controllers. But since the low operating power consumption, the MPPT efficiency difference could almost be negligible making it unnecessary for our design. PWM controllers also work well in warmer climates.

Now that we have the solar panel wattage, we will look at the next step which is the charge controller. To calculate the required charge controller, we look at the system amperage coming from the solar panel, and to do this, we will look at the voltage rating for the solar panel as well. Several assumptions need to be made to find the appropriate pieces for the solar system, because there can be many different options that work for our design. It was decided to use an 18-volt solar panel because this is one of the most widely available voltage ratings on the market for 100 watt solar panels and allows to work with most battery voltage ratings making the voltage regulation minimal between the solar panels and the batteries. Most industrial batteries found are rated for 12 volts so we will use 12 volt batteries. The solar panel should have a higher voltage than then the batteries so that way when the solar panels are under not absolute sunlight contact, they will still maintain a high voltage typically over 12 volts which will still charge a 12-volt battery batteries [124]. A graph was made showing the different voltages produced by the solar panel in different amounts of sunlight. The sunlight was varied by placing the solar panel in direct sunlight and then covering up rows of solar cells, for our solar panel there are 8 rows of solar panels:
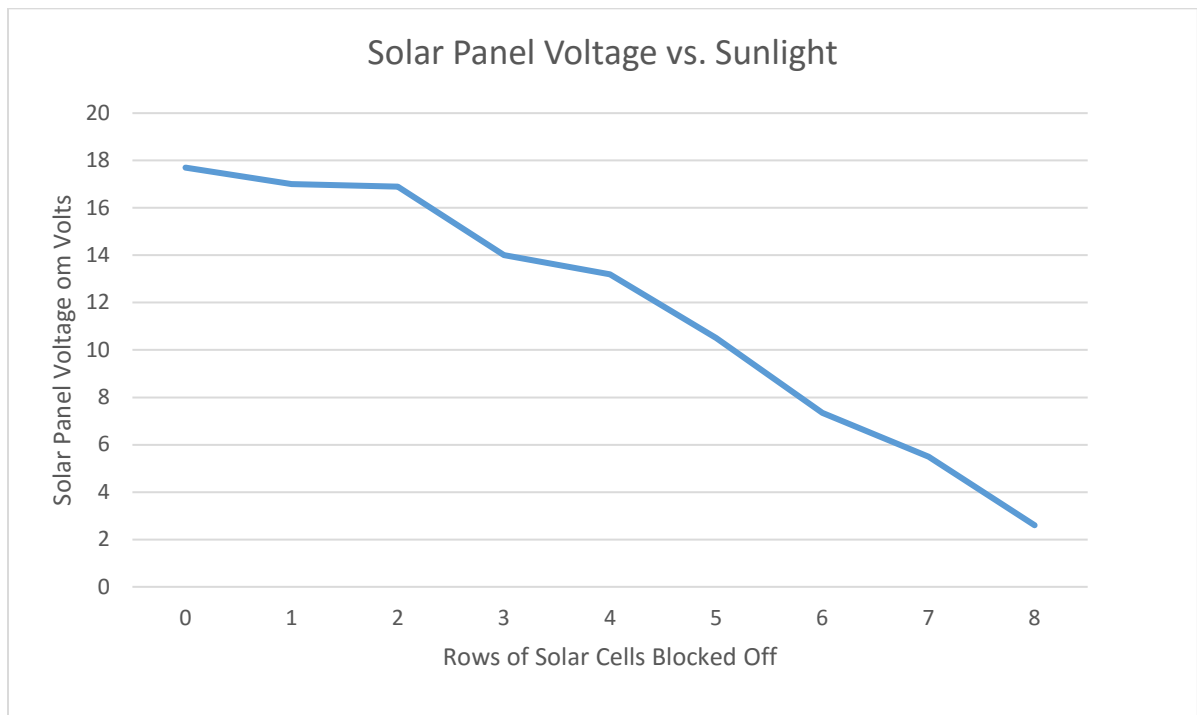

Figure 21. Graph of Solar Panel Voltage Against Rows of Solar Cells blocked off.

The current was also measured at different amounts of sunlight and recorded. It is clear in the following figure that the for this test, there was around 1 amp of current flow when there were two or less rows of solar cells blocked off. From the above figure, the voltage was 16+ volts. So the highest drop of current occurred when the voltage went to 14 volts when 3 rows of solar cells were blocked off.
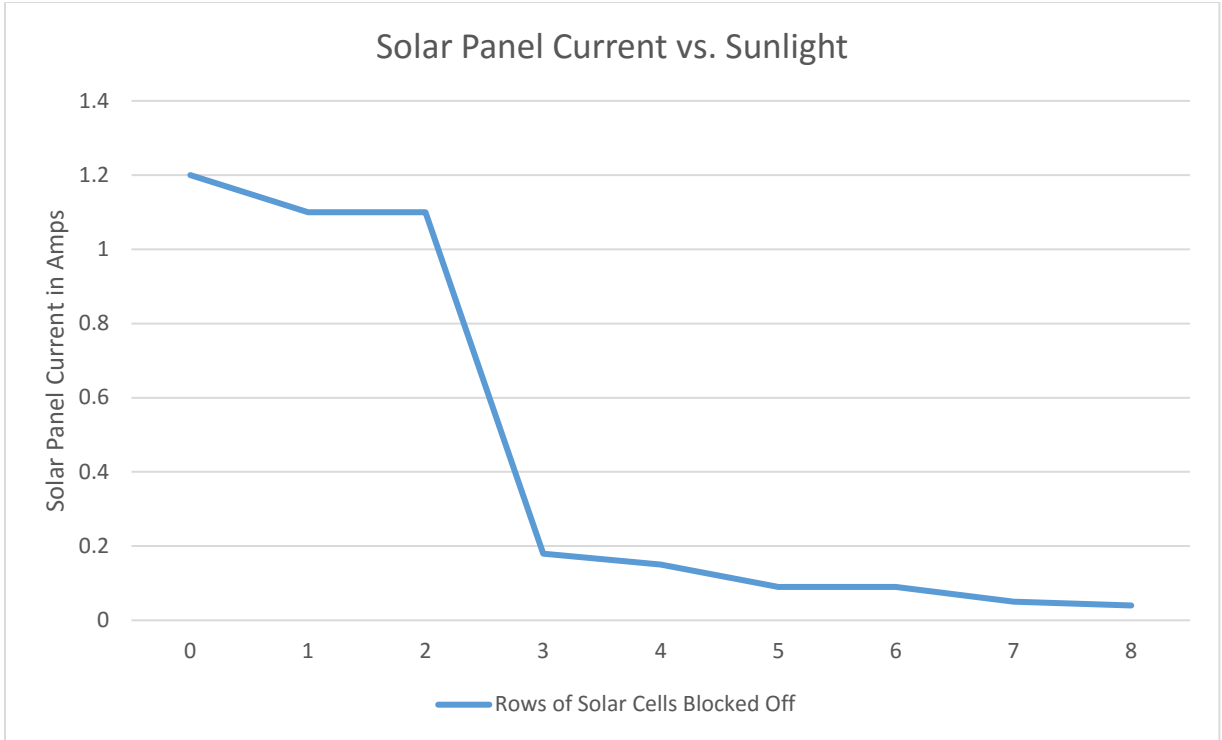

Figure 22. Graph of Solar Panel Current Against Rows of Solar Cells blocked off.

So now we have a solar panel, and battery that can get charged, but a charge controller is still required to make sure the batteries aren't overcharged/undercharged. Our charge controller must be able to hold more current than that which is calculated to be outputted by the solar panel. To calculate the amount outputted by the solar panel, we need to find the amp hours used per day. This can be found with the following equation where whd was calculated to be whd = 432 watthours, and V_{SA} is the solar array voltage which is explained to be V_{SA} = 18 volts [125]:

$$ah_{day} = \frac{whd}{V_{SA}} \quad \text{Equation 8}$$

Plugging in these values gives ah_{day} = 24 amp hours /day. Now relate this to the amount of direct sunlight received daily to get the current produced by the solar panel labeled I_{solar} [125]:

$$\frac{ah_{day}}{(sunlight\ received)} = I_{solar} \quad \text{Equation 9}$$

This gives a I_{solar} = 5.3 amps, now the charge controller must be able to carry this much current and some extra in case the solar panel produces higher amounts amount of current in bright sunlight, the charge controller current necessary is found below by adding to 20% of the current it needs to be hold where I_{cc} is the charge controller current [125]:

$$I_{solar} + 0.2I_{solar} = I_{cc} \qquad \text{Equation 10}$$

I_{cc} is then found to be 6.4 amps this will be assumed to be the maximum current for our solar panel at a voltage of 18 volts. 6.4 amps gives the minimum rating the charge controller should be able to handle [125]. We will use a charge controller capable of handling 18-12 volts so that it can handle the voltage of the solar panels and the batteries, and be capable of handling 6.4 amps. Looking at recommended charge controllers for the type of solar panel we chose we found the Mohoo 20A Charge Controller Solar Charge Regulator will be sufficient as it can hold up to 12-24 volts at 20 amps. We will start with a pulse width modulation charge controller primarily because they are cheap and the advantages seen from MPPT controllers might not be necessary in a small system under 150 watts like ours. Testing will be done on this controller when it is connected to make sure it is regulating the charge of the battery properly and does not destroy the battery from overcharging it.

The controller was bought and is shown in the figure below:

Figure 23 Mohoo Charge Controller that was bought and tested (Permission Pending) [126]

This charge controller was easy to connect to the batteries and has two USB ports that can be used to charge USB compatible components. The USB ports will not be used though because we want all four Raspberry Pi modules to be charged the same way to maintain consistency and prevent new charging problems from possibly arising by using multiple different powering methods. The Raspberry Pi modules will instead be powered through a wire connecting to the Micro-USB port on each module. Connecting wires to this charge controller were easy, by using a flat head screw driver, the wire connection slots were opened and each wire was appropriately placed in the right slot and secured.

As seen in the charge controller figure, each slot is labeled making it easy to know which terminal and which component goes where. The 4 holes in the frame of the charge controller will be used to secure the charge controller in place with screws to the frame of the design. There are three buttons on the charge controller that will be used to set the charging points. These charging points will determine when solar panel will stop charging the battery to prevent overcharging and then we will decide on a depth of discharge according to chart 1 to determine what the appropriate voltage needs to be set to in order to turn of powering the supply.

When this charge controller was connected to a load, battery and solar panel giving all the appropriate icons to display in the LCD screen proving everything is connected properly. According to the user manual there are three buttons that can be used to change the different voltage charging points. A button is used to switch between different settings, each setting changes the entire display. When no buttons are pressed, the charge controller switches to the main screen showing the voltage of the battery and which parts of the system are connected. When the solar panel reaches a high enough voltage to charge the battery, a small solar panel indicator arrow starts blinking on the LCD screen. When the solar panel is not charging, the solar panel icon and arrow go off the screen. Also on the main screen, are icons for the battery and an arrow from the battery icon to a load icon which all should be on to show that the battery and load are connected. In order to connect all components to the charge controller, extra wire was needed. 16-gauge wire was used to connect each component.

For this charge controller, it can change settings based on the type of battery that is being used. In order to set the correct battery, the sixth screen that shows up when going through the settings has three choices for batteries: b01, b02 or b03. After referencing the user manual that came with the product, it was clear that b01 was for sealed lead acid batteries. After setting this, the work mode screen was changed from 24 hours of operation to 5 hours a day that the load would need power. Next, the float voltage screen was set properly to 13.8 volts as explained that the float voltage level should be in the charge controller research section. Next the discharge reconnect screen was displayed and appropriately set to 12.6 volts and the discharge stop point was set to 11.6 volts. All of these values were found during research for a 12 volt lead acid battery [16]. They can all be adjusted within a safe range that would still allow the system to work if we wanted to expand the discharge range of the battery. Each setting was set by pressing holding the main

button for 4 seconds until the screen starting blinking, then there were two arrow key buttons used to adjust all numbers.

Since our system needs an external circuit to convert the 12 volts of the battery to 5 volts for USB compatibility, we did research on converters that would work for our load. To start, we need a converter that can supply up to 11 amps of current if our Load is running at maximum current assuming we also need an Ethernet switch powered as well.

5.4.3 Battery to Device

We will look for batteries that can work well and maintain efficiency in warm weather conditions as well as meet the required amp hour rating. Amp hours determine the size of the battery you need, this can also be determined by looking at the watthours a battery can hold [122]. To find our amp hour rating, we look at the amount of amp hours the Raspberry Pi modules will use each day which is 432 watt hours per day. We concluded that a 12 volt battery system would be best because those are the most common types when it comes to solar panels. Using the equation below, we can find the amp hours needed to charge the system [122]:

$$\frac{whd}{battery\ bank\ voltage} = ah_{day} \quad \text{Equation 11}$$

This gives a required 36 amp hours per day needed from the batteries to the modules. For our project we will ignore days without sun because this is going to be a prototype and adding in days without sun creates unnecessary extra battery capacity that is a waste of time, space, and weight for this design. So we will assume every day we get the same 4.5 hours of direct sunlight. We will also assume we will have a depth of discharge around 50%, normally a 50% discharge depth is optimal to make your batteries last as long as possible but for deep cycle lead acid, depth of discharge is used to explain what percent of the batteries capacity can be discharged before needing to be recharged. Using the equation below we can find the needed storage capacity of the battery [125]:

$$\frac{ah_{day}}{(Depth\ of\ discharge)} = ah_{batt} \quad \text{Equation 12}$$

This gives ah_{batt} (the battery capacity in amp hours) = 72 amp hours. We can also convert this to watthours, where PH_{batt} is watthours using the following equation [125]:

$$V_{batt} * ah_{batt} = PH_{batt} \quad \text{Equation 13}$$

Where V_{batt} = 12 volts, we get PH_{batt} = 864 watthours. 864 watthours is much higher than the needed 432 watthours each day, and after doing research, it was found that batteries with this type of capacity weighed anywhere from 40-60 pounds. So we will look at smaller batteries under 15 pounds even if they do not keep the design running for 24 hours. It was found that most batteries under 15 pounds had a capacity of 10 amp hours or 120 watthours. In order to make it so the battery is not a major weight concern, we will look for batteries that can for only 5 hours a

day instead of 24 hours. Using the equation below, we will be able to cut the watthours needed from 24 hours of operation down to 6 hours operation [122]:

$$whd\left(\frac{hours\ used\ each\ day}{hours\ in\ a\ day}\right) = whd_{new} \qquad \textit{Equation 14}$$

This gives a needed 90 watthours to power the design, and we can look online for batteries with a capacity higher than 90 watthours. Using the equation for PH_{batt} again, we can easily look online and calculate different watthour values for different types of batteries with their amp hour and voltage ratings. It was found that a 12-volt battery with a capacity of 10 amp hours was large enough for our design with a 120 watthour capacity. After looking at several different types of batteries, lead acid were found to be the common type for solar panels. Lead acid was also found to the most common for high capacity batteries and so an Expert Power 12v 10 amp hour SLA rechargeable battery was bought [127]. This battery is much lighter than the higher capacitor batteries weighing only 6 pounds so this is a good fit for our design so we can help meet the space requirement of putting everything in a thin case on top of a car. There was no official datasheet for this battery was given and could not be found, but the battery says it is rated for no more than 3 amps. If this is a problem when trying to pull current for the load, we will simply buy another identical battery and put it in parallel and the load will have enough current supplied. When building the design all together we will make note of this and see if this is needed.

The voltage across the batteries terminals was first measured using the multimeter and found to be 12.84 volts out of the box. We then bought some 16-gauge wire to connect the battery to the charge controller. We also connected wire to the outputs of the solar panel and connected this to this charge controller. This shows the battery is fully charged and we will use the following chart to determine the charge when testing and using the battery:

Voltage	State of Charge
12.6+	100%
12.5	90%
12.42	80%
12.32	70%
12.20	60%
12.06	50%
11.9	40%
11.75	30%
11.58	20%
11.31	10%
10.5	0%

Table 8. Different States of Charge of a battery based on the its voltage [128]

In order to connect the battery to the Raspberry Pi modules, a linear regulator converts to the appropriate voltage for the Raspberry Pi module, and a micro USB port is connected to the Raspberry Pi and the USB port is opened up and the wires from the regulator will be connect to the USB side.

5.5 Mobile Application Design

As shown above, the mobile operating system that we decided to follow through with is Android. Most notably the benefits of using Android over iSO and Windows Mobile is its widespread use and that each member of our group had easy access to an Android device for testing purposes. As well, experience working with both Android as a user / client and developer makes both the planning and implementation phases of product development much more straightforward to approach.

5.5.1 User Interface

The goal of our user interface is to accomplish the following tasks:

- Give the user the ability to arm their vehicle security device, activating its surveillance capabilities.
- Sound an emergency alarm from the device (not the personal mobile device).

- View the video feed coming in from the cameras.
- Configure the system to respond to the users desired behavior.

5.5.1.1 Menu Navigation

In the figure below we have our mockup design for the Android application interface. This will be the users primary access point to their device's configuration settings and input/output management.

Figure 24. Menu Navigation Mockup

Referencing the previously shown class diagram we can see the button presses that are available to the user:

- ARM – Arm the device and begin the routine to notify the user if the PIR detects movement within the vehicles proximity.
- Sound Alarm – Using the onboard speakers of the device, sound an alarm to attempt to deter any possible theft or vandalism to the vehicle.
- View Video Feed – Navigate to the video feed menu to allow the user to view the camera's display and see the vehicle's surroundings
- Power Down – Power down the device.
- Settings – Access the settings menu, allow the user to configure their device's behavior
- (X) Button – Exit the application.

5.5.1.2 Notification and Alerts

Displayed in the figure below is a mockup notification message caused by the device having its passive infra-red sensor triggered within the appropriate bounds. The user is notified visually of the action and is given the option to either dismiss the notification or open the application for further action. If the phone's screen is not active at the time then the default action will be to trigger a wakeup and open the screen.
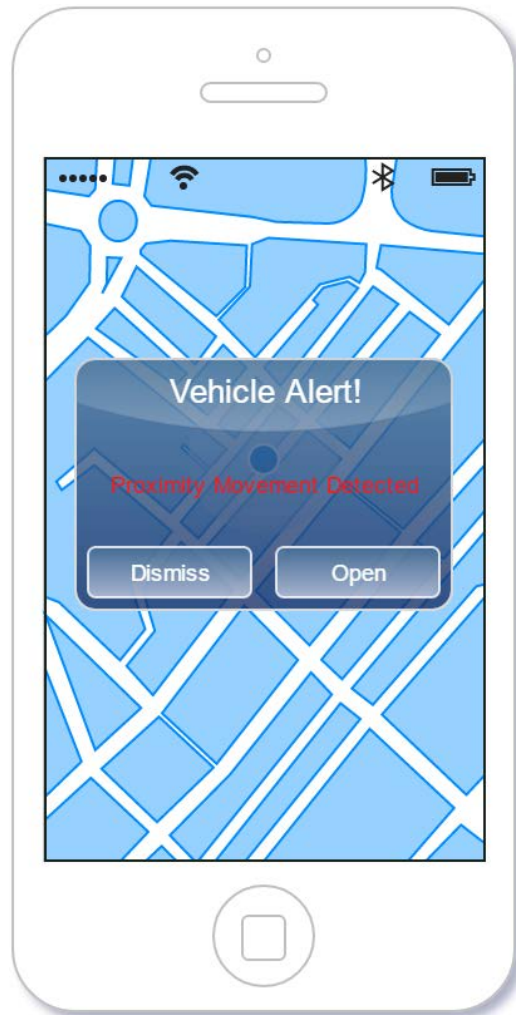
Figure 25. Alert Popup Notification

5.5.1.3 Video Feed

Shown below is a mockup display of the video feed displayed to the user. This will be the primary output to the user, allowing them to view their vehicles current surroundings and the history stored on the device as well.
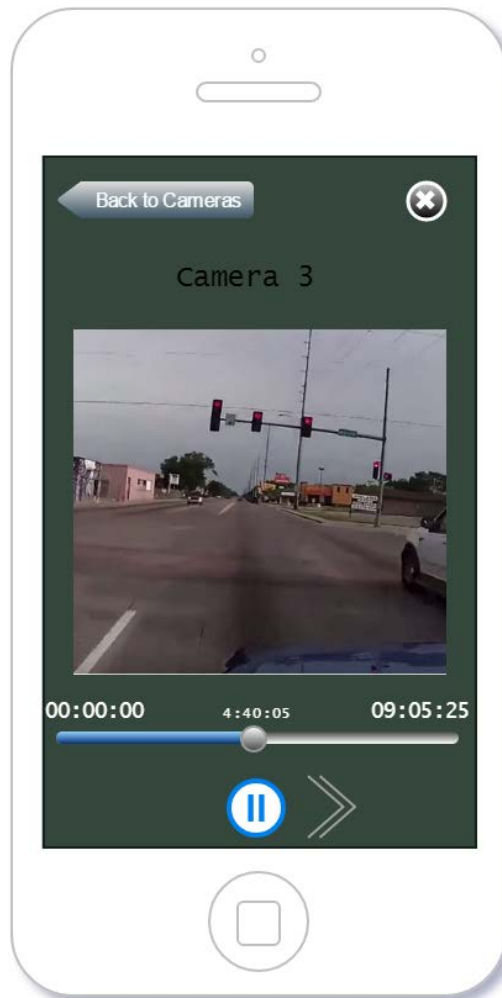
Figure 26. Video Feed Mockup

Within the video feed menu, the user has the current options available to them:

- Back to Cameras – Return to the list of cameras and their associated video feeds.
- (X) Button – Exit the application
- Pause – Pause the currently streaming / playing video feed.
- (>>) Button – Pressed once will speed up video speed, double pressed will skip to live footage (if available)
- Seek Dial – Dragging this dial will allow the user to seek through the available video footage.

The Android application will give the user the opportunity to receive notifications when the cameras have been activated and started recording. The application will also give the user the opportunity to see a livestream feed of the surroundings of the car. The Raspberry Pi will also store the videos in different time slots. When the SD card is filled, the Raspberry Pi will delete older videos from the storage device.

84

Video Streaming will be done over using User space Video4Linux Collection, also known as UV4L. UV4L was originally a collection of Video4Linux2-compliant, cross-platform, user space drivers for real or virtual video input and output devices. This has evolved during the time and now includes a full-featured Streaming Server component providing a set of modern and unique solutions for encrypted live data, audio and video streaming over the web and for the IoT era. UV4L supports HTTP and HTTPS protocols and can be programmed and controlled using a RESTful API. This is a robust solution due to the fact that it supports many livestream formats such as JPEG, MJPEG and WebRTC [129]. This module also has the possibility of enabling a per camera streaming server that can be accessed by any browser over HTTP or HTTPs protocols. This is of great usefulness due to the fact that the system will contain more than one camera and there will be cases in which more than one camera will be activated and record video that would need to be sent to the application.

The UV4L documentation page makes it very easy for the developers to set it up. It comes with a server that can stream MJPEG. This format is supported by web browsers and it can easily be integrated with the Android app using a tool called WebView.

5.5.1.4 Communication Software Standard: ISO/IEC 14766:1997

The International Organization for Standardization (ISO) is an organization that sets specifications to ensure efficiency as well as safety for many different types of products. The International Organization for Standardization join together with the International Electrotechnical Commission (IEC) to create the committee ISO/IEC.

The Standard ISO/IEC 14766:1997 will be followed during the development of the communication system that connects the Raspberry Pi to the Android Application. This standard provides guidelines for telecommunication and information exchange designed to allow the Open System Interconnection (OSI) upper layers to operate on the Transmission Control Protocol without knowing that it is operating on the Transmission Control Protocol Internetwork [109].

Because we are using TCP to transmit information from one system to the other, it is very important to follow this Standard in order to create a secure and reliable connection to transmit and deliver video from the security system to the user's application [109].

5.6 Wireless Communication

When comparing wireless communication techniques between Bluetooth, Wi-Fi, and GSM networks, each had their own pros and cons with respect to development, maintenance, and overhead ownership. In the case of this device, GSM was found to be the most relevant due to its range of connection. As a mobile vehicular security system requiring a tether to either a Wi-Fi router or Bluetooth device would heavily restrict its use.

5.6.1 GSM Network Communication

To establish an internet connection via GSM Towers and the cellular network, this project will be utilizing a GSM dongle, or unlocked USB modem, with an equipped SIM card.

Figure 27. Vodafone K3772 Mobile Dongle (Permission Pending) [130]

The dongle will be equipped to the master node of the Raspberry Pi Cluster with an attached SIM card. The service provider used for development purposes will primarily be Cricket, which uses AT&T cell towers. However, testing will be made to ensure the device works using multiple different SIM configurations and service providers.

Initializing Network Connection

To configure the dongle to act as a modem, the USB_ModeSwitch tool will be utilized. This tool is used for controlling USB devices that have multiple different operating modes. In this case it will ensure consistent behavior of the GSM dongle so that it does not behave as a storage device. To install the mode switch tool the follow console command will be entered into the linux shell: `sudo apt-get install usb_modeswitch`

Next, Point-to-Point Protocol will be installed, which will handle our internet service, using the following console command: `sudo apt-get install ppp`

Once completed, a configuration file will need to be created for the tool which will configure the USB modem upon startup. Using the command `lsusb`, we will find a return in the console along the format of:

```
Bus 002 Device 002 ID 1b6a:2514 <Company Name>
```

In the example above we will need the two fields after ID, which will gives us our DefaultVendor and DefaultProduct. DefaultVendor in this case would be 1b6a and

DefaultProduct 2514 respectedly. The <Company Name> is verified to match our dongle creator, in our case Vodafone. The next step will be to append these exact MessageEndpoint and MessageContent fields to create the following config file in the */etc/usb_modeswitch.conf* directory. First, create the file using `nano /etc/usb_modeswitch.conf`

Then, enter the following text

```
DefaultVender   = 0x1b6a
DefaultProduct  = 0x2514
MessageEndPoint = "0x01"
MessageContent  =
"55534243123456780000000000000001106200000010100010000000000000
```

We will then need to configure out Point-To-Point Protocol. We will create our PPP configuration file in the /etc/ppp/peers/Vodafone directory with the following content:

```
user "internet.vodafone.ro"
password "Vodafone"
connect "/usr/sbin/chat -v -f /etc/ppp/chatscripts/vodafone2"
noipdefault
ipcp-no-addresses
maxfail 40
persist
ipcp-accept-local
ipcp-accept-remote
noipx
usepeerdns
defaultroute
replacedefaultroute
```

Once completed, we'll be able to open the ppp interface using the following console command `ifup gprs` which will display packet and network information. [131] [62]

5.7 Peripherals

5.7.1 Cameras

The core of our project lies with the cameras. Our project relies on the cameras to view and record possible criminals trying to break in. Because of this, we needed to be sure that we got a camera that was able to meet all of our requirements. Some of the main requirements we used when making a decision on our camera were the following:

- Image Quality – Resolution, framerate, and pixel count.
- Field of View – Focal length and viewing angle.
- Power Consumption – How much power is consumed when running.
- Budget – The price of each camera

The most important of these requirements was the image quality. When making a project that is based around recording in order to try and secure an object, image quality is super important. We needed to make sure we got a camera that had a high enough quality and resolution when streaming so that the criminal being recorded can be made out. Trying to stream with a camera that is low quality can defeat the whole purpose of security. We also wanted to make sure that we got a camera that had a large enough field of view that we believed could cover all important areas of each side of the car. Having too small of a viewing angle can cause things to be missed. The power consumption is important as well since we want to make sure our system is as efficient as possible. The price wasn't as big of an issue, however, since we were planning on buying four, we wanted to use our budget wisely.

After taking into consideration all of our requirements, we decided on going with the Raspberry Pi Camera Module v2. This camera we believed fit all of the requirements we were looking for in mostly ideal ways. We were on the edge about several different ones, but in the end decided on the Camera Module v2. The specifications are given below:

- Price – The price of the Camera Module v2 is extremely low when comparing to other cameras. The module comes at $25 a camera. Most of the other cameras we were looking at came at a price of around $40 on average. This low price is significant in allowing us to spend a little more on other parts. We would be saving an average of $60 if taking into account of having to buy four. The price is surprisingly low when considering the utility it brings.
- Size – Another significant difference between the Camera Module v2 and all the other cameras we looked at was the size. The module comes at a very compact size of 25mm x 24mm. Every other camera we looked at was 38mm x 38mm. This smaller, compact size allows us the flexibility of integrating it much easier into our design. It also comes very bare bones, with the device coming only with what's needed, and is very flat. This was another perk we loved as it allows us to easily integrate it into our system. It weighs a negligible 3g, making it the lightest of all the cameras we viewed as well.
- Power Consumption – The Camera Module v2 is very convenient when it comes to power consumption. With most other cameras we looked at, the cameras all had to be powered through either a GPIO pin or USB. While this doesn't sound like a problem, it had the possibility to pose issues. The Camera Module v2 is the only camera that work sdirectly with our Raspberry Pi. It is attached to the Pi via a ribbon cable into the designated camera module port. This port then supplies the needed 5V and 250mA in order to run the camera. Most other cameras we viewed needed higher currents in order to operate. The USB ports on the Raspberry Pi all had the capabilities to supply the correct current, but the extra current expended on the USB ports could waste unnecessary power.

- Image Quality – The quality of the image was our biggest concern when looking for a camera. The camera module excels at image quality. It runs at a smooth rate of 30-60 frames per second. The lowest framerate we decided would be acceptable is 30 frames per second. This camera has the option to film up to 60 which is way over than what we were expecting. It also has a really high pixel count at 8 Mega pixels. This means it has roughly 8 million pixels used for capturing an image. Most other cameras we were looking at had around 2 Mega pixels to 5 Mega pixels. Having a higher pixel count means for much clearer picture. Not only is the quality of capturing the image high, the camera module also has a high streaming resolution. It has the ability to stream 1280 x 720 at an extremely smooth 60 frames per second. It even has the capability to stream 1920 x 1080 at 30 frames per second. This was huge in the decision for buying this camera. Both resolutions the camera has the ability to stream at are ideal. "High-definition" quality starts at 1280 x 720, meaning that even if we decided on going for the lowest quality available on this camera, it still will be clear. The 60 fps makes sure that the video runs as smoothly as possible and allows for perfect capturing of each second. Most other cameras we looked at could run around 30 fps at their max resolutions, with 60 fps only being available to a few. The ones that were able to run on a faster framerate also had very poor quality.
- Field of View – The field of view is where the Camera Module v2 lacks in the most. When looking for cameras we knew we had to have a camera that had a large enough view of angle to cover all of the car. The camera module v2 has a focal length of 3.6mm. This is a slightly large focal length when considering the other cameras we looked at. Most other cameras had a focal length of around 2.1-2.3mm. The focal length is a determinate in how much of a viewing angle the camera has. Because of this slightly larger focal length, the viewing angle of the module is roughly 60 degrees. This angle of course isn't exact, but is small. The other camera we viewed that had a focal length of about 3.6mm had a viewing angle of about 75 degrees. This poses a small issue since we'd possibly miss out on coverage. The other cameras we looked at all had viewing angles of 150 degrees or more. This means that they would all cover all of the car and even overlap into each others' field of view. While this is ideal, we found when looking at cameras with larger viewing angles, there seemed to be a drop in quality. In order to have such a wide field of view, the camera has to distort the image slightly to look like a fisheye. This can cause images to distort. We decided that having a viewing angle of roughly 60 degrees, while small, should be sufficient for covering each side of the car efficiently. What we lose in field of view, we gain in the amount of quality being shown through the image.

Set-up

Our project consists of a total of four cameras. Each of these cameras will be linked to its' own individual Raspberry Pi Model B. Since our cameras attach to

the Raspberry Pi via a ribbon cable, and since each Pi only has one port, we decided this is the best way to do it. We also decided on having multiple Pi due to the processing power needed in order to stream all four videos at once. Each of these cameras will be placed so that each camera can get a good angle of the car, see Figure [whatever] below. We wanted to make sure when setting up the cameras that we had a good enough view of the car.
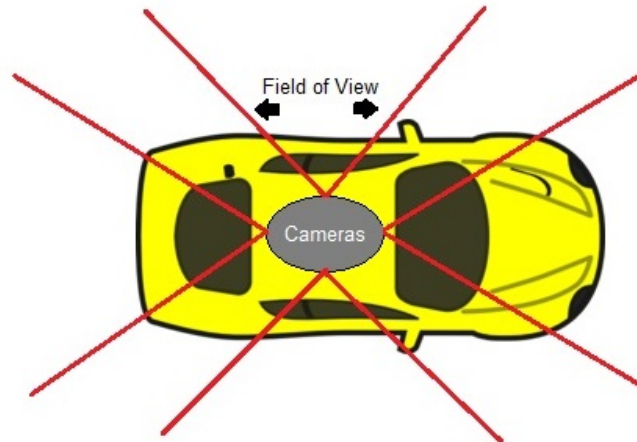

Figure 28. Field of View (Created using free Clipart)

In order to make sure that the cameras aren't running at all times, each camera will only be activated by the PIR sensors. Each camera will be paired with a PIR sensor. Once the PIR sensor detects movement, the Raspberry Pi will tell the cameras to start to record. The cameras will continue to record for a period of time. Once the PIR sensors and the IMU don't detect there to be any more threat, the cameras will stop recording. In order to ensure that the cameras aren't recording while you are approaching the vehicle and the entire time you are driving, the microcontroller will ping out Bluetooth signals to your device until it recognizes it is in the area. Once you are in the area, the cameras as well as notifications will cease. The video will be fed directly to the users' devices. The two main resolution we are to choose from are:

- 1280 x 720p at 60 fps
- 1920 x 1080p at 30 fps
- 640 x 480p at 90fps

We decided that most phone devices don't show quality much better than that of 1280 x 720p due to their limited screen sizes. The 640 x 480p quality is a little low for what we want, even though it streams at an over-the-top 90fps. We could go for the higher resolution of 1920 x 1080p, but decided the loss in frames isn't worth the hard to differentiate difference in resolution.

Front Camera

One interesting addition to our build is the front camera. Our front camera will work the same as the other cameras when the car is idle. Once the device contacts the user's mobile device and determines the person is close by in the area, the front camera will have the option to turn into a sort of dash-cam. Every other camera will turn off, but the front camera will stay on and record while the user is driving. The video being recorded will constantly be saved into the hard drive, and as the memory gets full, will overwrite itself. This allows for the camera to keep recording without running out of memory. The addition of the dash-cam front camera allows for our system to not only secure the car while it is parked, but also record all possible moments while driving for insurance. If the user wants to view the recorded footage the will have the option to do so.

5.7.2 PIR Sensors

PIR sensors will be used in order to detect initial movement near the vehicle. This motion detection is useful for first turning on the cameras and getting them recording. Most PIR sensors on the market are very similar, and there are only few real differences here and there. We looked at several different models until we decided.

We decided on using the DSN FIR800 model. This model was similar to others, but came with the option to adjust settings manually with two sets of switches. The specifications of the PIR are as follows:

- Price – The price of the DSN FIR800 was one of the main reasons we decided on them. Most PIR sensors are relatively cheap, but we got 5 for the price of $8. Not only is it cheap, but allows us to have an extra for back-up.
- Size – The PIR sensor is about normal size for a PIR sensor at 32mm x 28mm. This small design allows us to integrate it with our system much easier. The sensor is also very lightweight.
- Power Consumption – The PIR sensor runs at an operating voltage of 5V. However, the PIR is a passive device, meaning that while it is idle and doesn't detect anything, there is no power consumption. This is a main reason we went with PIR sensors as it saves a lot of energy.

Set-up

We will have each PIR sensor attached to its' own Raspberry Pi. Each one of those Pi will also have its' own camera. Once the PIR sensor detects movement, it will send a voltage to the microprocessor informing it to turn on and start recording with the cameras. The PIR sensors allow for a first line of detection. The will ideally detect motion from up to 2 meters.

5.7.3 Speakers

Our project, like many other security systems, will utilize audio outputs. In our design, we would like the user to have the ability to set off an alarming sound when

prompted that their car could be in danger. This is intended to potentially scare off the suspect. In order to do this, we will be using speakers integrated in our design.

After some consideration, we decided on going with the Raspberry Pi USB Powered Speakers. There were several speakers we looked at, but most didn't run on the power requirements we were looking for. A lot of others that worked on low power consumption wouldn't provide enough volume to be heard properly. The specifications of the USB speakers are as follows:

- Price – The speakers came at a great price of only $10. This is an outstandingly low price for the quality of the speakers. Most other speakers we looked at didn't fit our criteria and still priced at around $15.
- Size – The speakers are rather bulky. There are a total of two speaker heads, each coming at a size of 69mm x 80mm x 85mm. We are going to try and remove any unnecessary parts and reduce the size. Even at this size, they are small enough to be integrated into our system.
- Power Consumption – The speakers work well with the Raspberry Pi as they run on around 5V. The speakers also need a current of around 200mA to run. However, to reach full volume, a current of around 1.0A is needed. The Raspberry Pi USB output has the necessary output current in order to supply this. This was a huge factor in deciding on these speakers.
- Quality – The speakers are good quality for the price. The have a frequency response of 100 Hz – 18 kHz running at 3 Watts. This is a relatively good range. This range will produce good highs and mediums with decent lows. Since our project doesn't require a lot of bass, this range is ideal. It also has an impedance of 4 Ohm which is very ideal since most have an impedance of only 8 Ohm. The sensitivity of our speakers are approximately 83-87 dB. 90 dB sensitivity is very high quality speakers, so having around 83-87 is decent. The quality of the speakers are ideal for our project.

Set-up

We will have the speakers set-up to the "main" Raspberry Pi. The Raspberry Pi comes with an audio port built-in, so set-up is pretty straight forward. Power for the speakers will also be given through the USB port from the Pi. Once the IMU detection is triggered and the user is prompted with a notification, the user will be given the option to sound an alarm. This option will cause the Raspberry Pi to play an audible alert through the speakers. This alert is intended to scare of the suspect as they now know someone has their identity. The speakers will be located somewhere within the design, but not obstructed as to allow for the noise to be heard.

5.7.4 Vibration Detection

For our design, we are using an IMU, or Inertial Measuring Unit, in order to pick up on vibrations caused from suspects trying to forcefully enter a car. An IMU consists of several different motion sensing devices including a gyroscope and an

accelerometer. With projects like ours that consist of needed accurate vibration detection, having an IMU is the best way.

We looked at several different models until we ultimately settled on the BerryIMU. The BerryIMU is an IMU that is specifically designed to work well with the Raspberry Pi. This was a major contributing factor to our decision in picking the IMU. Since IMU consist of many different vibration sensing devices, the information and coding for an IMU can be difficult. The BerryIMU simplifies it a little bit allowing for easier readings on the Raspberry Pi. Not only is it easier to use, but also comes with very good specifications:

- Price – It comes at a relatively low price of $25. This is cheap when comparing to other IMU we looked at. Most ranged between $30-$40.
- Size – The IMU comes at a pretty compact size at only 17.4mm x 34.25mm. This means the the IMU is slightly smaller than our Raspberry Pi. This allows for cleaner and easier implementation to our system. It also comes at a lightweight 3 grams.
- Power Consumption – The IMU only needs 3.3V to supply it. This is very low when considering most other peripherals we used needed 5V. This works perfectly with our Raspberry Pi as it has a 3.3 V output GPIO pin.
- Quality – The BerryIMU excels in quality. It has a sensitivity as low as 8.75 mdps and goes up to 70 mdps. This means that the gyroscope has the ability to pick up very small motion. The accelerometer of the device has a rate of ±2g, ±4g, ±6g, ±8g, ±16g. This means that the accelerometer has a wide range of motion it is able to detect. This range is larger than most other IMU we looked at. The IMU also has a total of 6 axes it can detect on. This means it able to detect not only acceleration on the X, Y, and Z axis, but also rotation. This is very useful to have, as it allows for the most accuracy possible.

Set-up

We will only have one IMU in our design. We only need one in order to detect the vibration coming off of the vehicle. The IMU will be set-up to the "main" Raspberry Pi. Once the IMU detects vibration, it will communicate with the Raspberry Pi to inform it to send a notification to the users' mobile device. The IMU is the last line of motion detection. Once the IMU determines someone is messing with the vehicle, it essentially confirms that what is being filmed can be determined as a security breach. All video being recorded is then also sent to the mobile devices.

5.8 Data Storage

The storage device that is going to be used for the implementation of the Automated Vehicle Anti-Theft Security System is the SD Card. Although, HDDs and SSDs have more capacity than SD Cards, this large capacity of over 60 GB is not needed. The microcontroller has a MicroSD module available that makes the interfacing of the Pi and the SD Plug and Play. The Raspberry Pi needs an Operating System to run on and this is most commonly installed and stored on a MicroSD Card. The Raspbian Operating System is about 4GB and the rest of the

storage availability would be for the software needed to program the microcontroller as well as to store the video that the camera records. The capacity needed for this would be at least 8GB. SD cards with capacity of 8GB or more can be acquired at a low cost in order to stay under budget.

There are three kinds of Speed Classes, "Speed Class", "UHS Speed Class" and "Video Speed Class" for SD and MicroSD cards. Actual transfer speed varies. Speed Class and UHS Speed Class provide the constant speed necessary for video recording by designating a minimum writing performance so that minimum and constant speed could be achieved for camcorders, video recorders and other devices with video recording capabilities under the conditional write operation specified in the standard [54]. Speed Class is marked with Class 2, 4, 6 and 10, UHS Speed Classes is marked with U1 and U3, Video Speed Class is marked with V6, V10, V30, V60, and V90. Figure 5b below shows a table defining standard speed classes among different SD Cards [54].

Figure 29: Figure 5b: Table containing write speed across SD cards. Permission pending from SD Association

The system needs to have a MicroSD Card that possesses good read speed to be able to process and read the software needed to run the Microcontroller and execute the required tasks such as activating cameras, recording video and video processing. The MicroSD Card must also have good write speed in order to store the modified data and created outputs that will need to be processed in the future. These are the two main metrics along with Capacity that characterize storage

devices and in this case SD Cards. Those three metrics are the main contributors of the group's decision related to Data Storage. Although price is a factor as well for considering parts of our project, price does not affect much in the decision making of which MicroSD card to buy because the price change across different SD Cards is not as much as the price of choosing an SSD over and SD card.

After taking into consideration capacity and speed class of the MicroSD card as well as Raspberry Pi class recommendations, a 32GB was selected to be the MicroSD card used to install the Raspbian OS as well as store the software and video on the microcontroller. The model is a Samsung EVO+ 32 GB microSD Card. This card has Class 10 and UHS-1 compatibility and is able to achieve up to 80MB/s of read speed and up to 20MB/s of write speed. The capacity is enough to satisfy the system data storage requirements. The card will contain the necessary Raspbian OS, the software that will activate the system peripherals and process the video that will end up being stored as well in this device. This system is deals mainly with video and MicroSD and SD cards in general are used popularly for photo and video storage. We do not know how much video will be captured by our system; therefore, having that extra storage available to hold video besides the crucial Raspberry Pi software is a great advantage. This card is water resistant and is also able to withstand temperatures up to 85 ° Celsius. This is a great advantage because our system is designed to be on the outdoors of a car. In a state like Florida, there are always high temperatures and storms and it is very important to us that the components are able to resist these climate conditions even though they will be protected and under the System Chassis. This part was acquired at a price of $15.99 and is pivotal for the programming of the microcontroller and the development of the system.

5.8.1 SD Association SDHC Standard

The MicroSD Card, along with any other storage devices, has to be formatted with a specific file system. The MicroSD card formatting that will be used in our system will follow the SD Association File System Standard. The SDHC Standard focuses on the capacity and file system for the SDHC cards. These storage cards, that have a capacity ranging from >2GB and 32GB, must contain a FAT32 file system. The Samsung EVO+ 32GB MicroSDHC cards that will be used for the System will be formatted to have a FAT32 file system in order to follow the standard created by the SD Association. Free formatting software called SD Card Formatter is provided by the SD Association in order to comply with the capacity standards of the Association. This software will be used to format all the microSD cards used before storing any data inside them [54].

5.9 System Chassis

connect the components securely to the frame of the design. The chassis will have a curved design on the top and bottom to fit onto of the curvature of a car. Metal

frame bars will run inside the case to strengthen the structure. Here is realistic sketch for our chassis design:
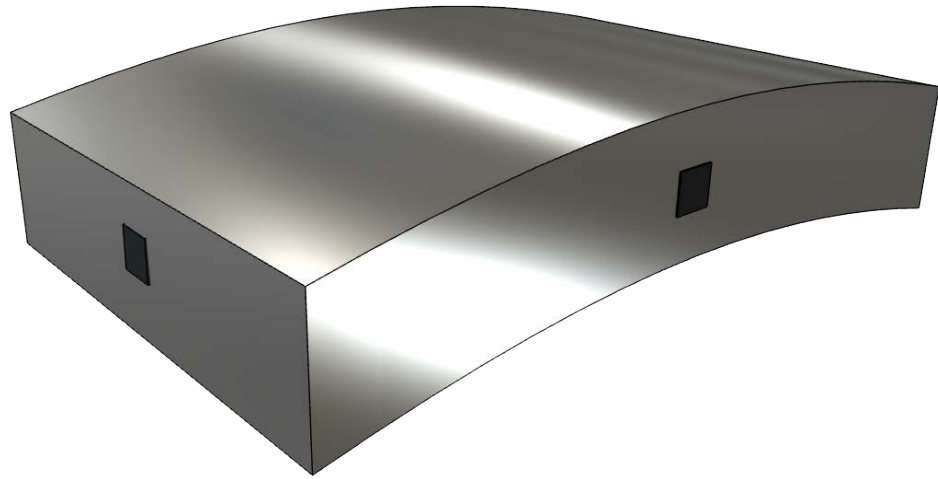

Figure 30 Screenshot of chassis design (Created in AutoDesk) [132]

As shown in the figure, the chassis will be made of the same material on each side, either made of metal or hard plastic. Most likely metal will be used because it is more durable. This is to scale 2.5 feet wide by 4 feet long at 8 inches tall. Two flat sheets will be bent to the curve shape and will have custom made sides from The top may be changed to a flat surface to make more room for framing. There are also small square on the sides to represent holes where cameras and sensors will be as seen in the figure. Next, a sketch up of the interior with the frame outlines was made. The blue bars in the figure show where the mounting rails will be placed.
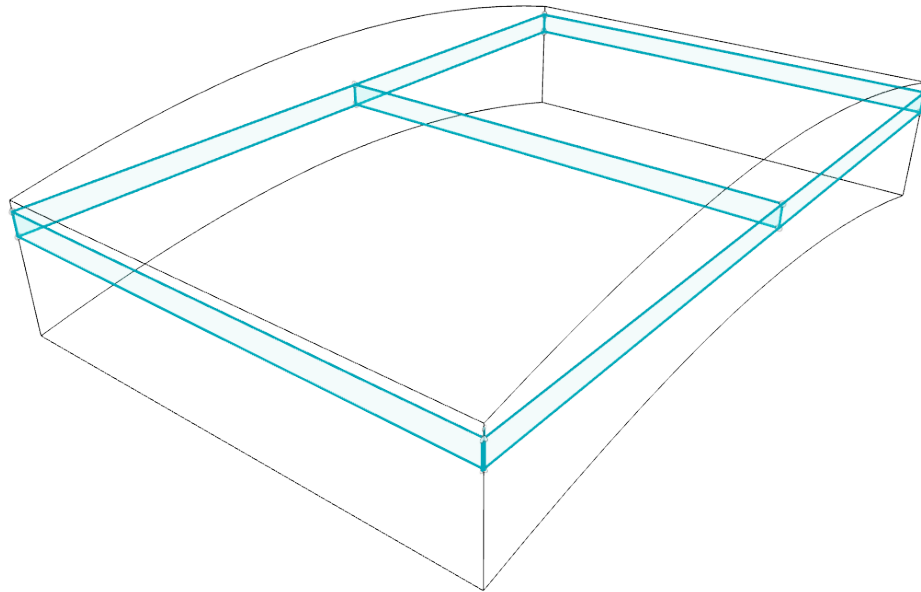
Figure 31 Screenshot of chassis frame design (Created in AutoDesk) [132]

Each component has holes where screws can be used to secure them to a frame using the appropriate type of screw. We will use Middle Atlantic RRF2 Space Rackrails which have screw in holes across each rail [133]. We will plan on using a custom metal cutting service after purchasing the necessary sheets of material [134].

6.0 Project Prototype Construction and Coding

6.1 PCB Vendor and Assembly

Because our charge controller cannot convert the necessary voltage to the load, an external circuit will be needed to convert the voltage. We are using 4 linear voltage regulators that will each convert voltage from 12 volts to 5 volts. One linear regulator will be used for each Raspberry Pi Module. A schematic of one linear regulator was first tested at various inputs to ensure that the circuit works and gives a constant 5-volt output.

The linear regulators will be connected to the charge controller and not directly to the battery in order to ensure they do not discharge the battery too much; Because if we connected them straight to the battery, the load would keep drawing more power until the battery was completely dead. Instead, the linear regulators will be connected to the load slots of the charge controller in parallel with each other, this will protect and turn off the load when the battery is at a low charge. Most regulators that were found for producing 5 volt outputs only run at a maximum of 1-amp output. However, each Raspberry Pi may need more than 1 amp to run so the next highest rated voltage regulator was chosen. The LT1085 was a component found that can produce voltage Using the LT1085 regulator, we can adjust R1 and R2 (shown in the schematic) to give a specific output voltage. For 5 volts, R1 was set to 121Ω and R2 was set to 365Ω. The equation for V_{out} for the regulator is shown below [135]:

$$V_{out} = 1.25 \left(1 + \frac{R2}{R1}\right) \qquad \text{\textit{Equation 15}}$$

Using the schematic given in the LT1085 datasheet to change the output voltage, a basic circuit was built. Here is a schematic of the design created in the Multisim application:
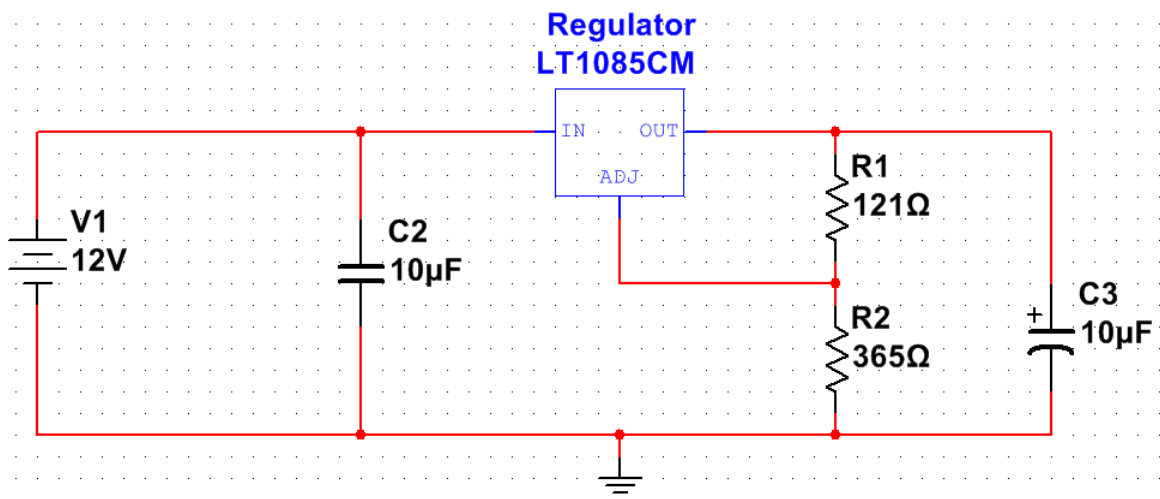

Figure 32 Schematic of Adjustable Linear Regulator [135] & [136]

98

The external components were added in order to regulate the output voltage and current using the schematic given in the datasheet for the LT1085 [135]. This design was tested with the values shown above and the output voltage was measured. The output current for this design was checked to make sure it can supply at least 2.5 amps to the load. As shown in table 3, the maximum output current was measured at different voltage levels. Each output current value is more than enough to power the Raspberry Pi module exactly what we need. Next, the input voltage was varied from 11.6 volts to 12.8 volts. 11.6 volts was chosen as the lowest voltage number to test at because that is the voltage our battery will be at when it is at 20% charged according to chart 1 and we will not go under this value. Likewise, 12.8 volts was chosen as the maximum voltage to test at because our battery at 100% charged should not be any higher than this voltage. Table 3 below shows the output response at different input voltages:

Input Voltage (Volts)	Maximum Output Current (Amps)	Output Voltage (Volts)
11.6	3.607	5.001
11.8	3.571	5.001
12	3.533	5.001
12.2	3.493	5.001
12.4	3.452	5.001
12.6	3.41	5.002
12.8	3.366	5.002

Table 9 Table of Input Voltage against Output Voltage and Output Current of the simulated circuit when the Input Voltage was varied

Table 3 shows that this device is stable and should work well with the Raspberry Pi supplying a constant 5 volts. The output current was also measured with different loads and found to range from 0-7 amps. So given all these measured values, the designed circuit will be able to safely power all components constantly.

Next, the entire PCB schematic was created with four of the adjustable regulator circuits put on one board. Bare wires will connect to pins from the battery to the PCB and then, each will have a USB socket for the output to the load. These USB sockets for the output will be used to make it easier and safer to connect from the load components to the PCB. 4 USB to Micro USB cables will be used to connect the PCB outputs to the Raspberry Pi modules. To make the PCB design, each footprint was made for each resistor, capacitor, regulator and connector. Then the circuits were automatically transferred over to Ultiboard and configured properly [137]. The trace thickness for the wire was measured using an online calculator [138]. It was found the necessary width would be 65 mil to handle 2.5 amps using

a trace thickness of 1.37 mils (A mil is a 1/1000th of an inch) [138]. Here is the schematic view in Ultiboard where the green traces are the top copper layer, and the red are the bottom copper layer:
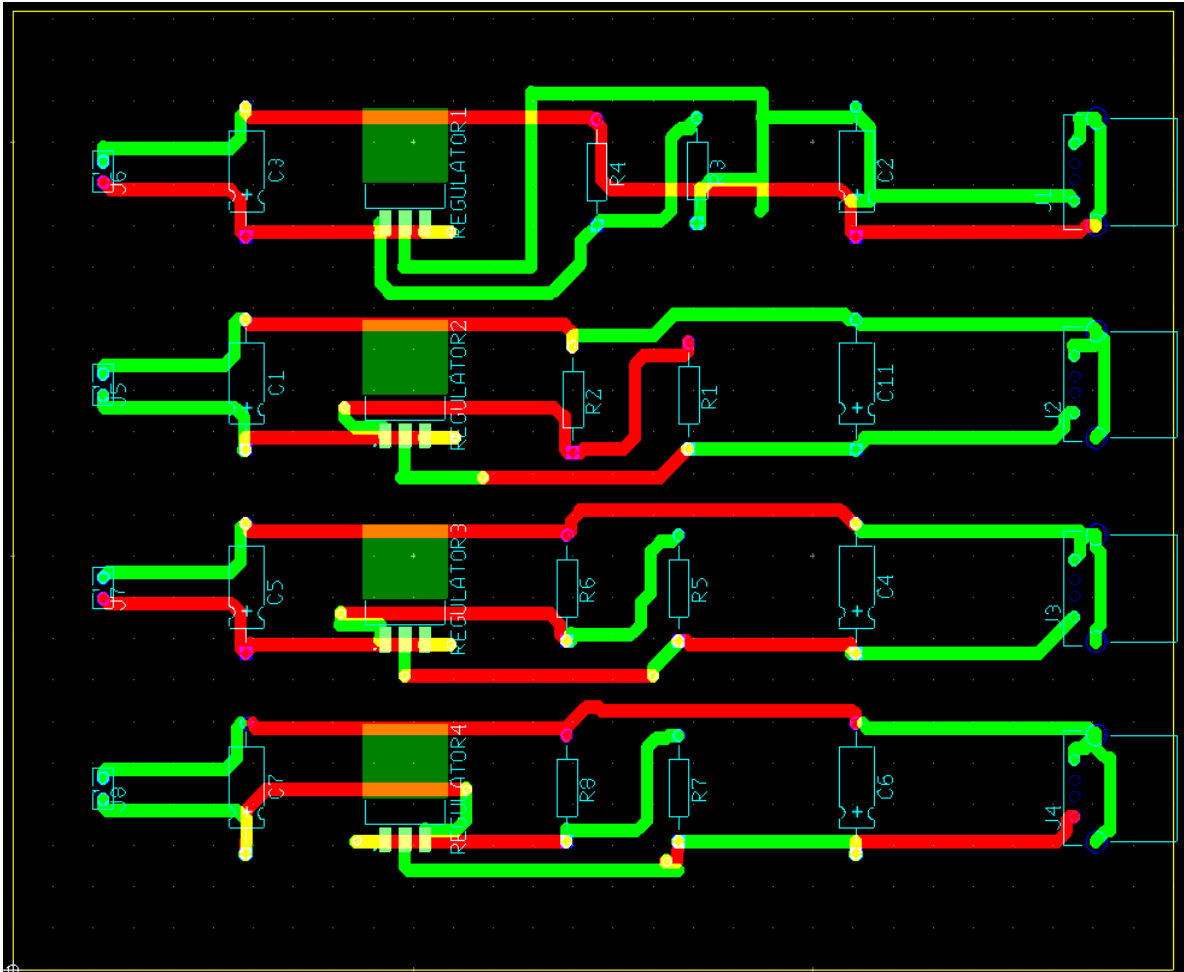

Figure 33 Schematic of 4 adjustable Voltage Regulators on one board for our PCB design [137]

To better visualize the design, a 3D preview of the design is shown in the figure below where the pins on the left represent the input terminals which are properly labeled and the right white boxes represent the USB terminals for outputs:
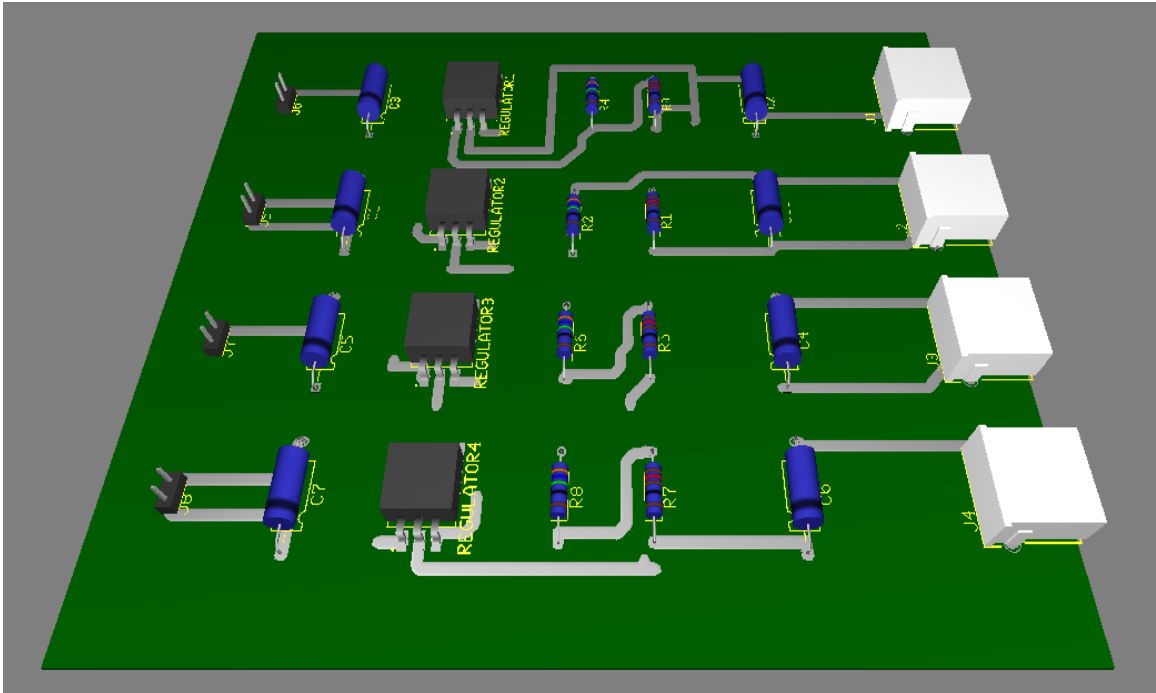
Figure 34 3D preview of PCB layout Schematic [137]

A physical circuit was also built to verify the results simulated. Breadboard implementation using a similar regulator was built because our regulators have not come in yet. No 3 amp regulators are readily available so a 1 amp regulator was used with the same type of circuit. The LM7805 component was used which has a very similar circuit to control the output voltage [139]. Here is the implementation on a breadboard:
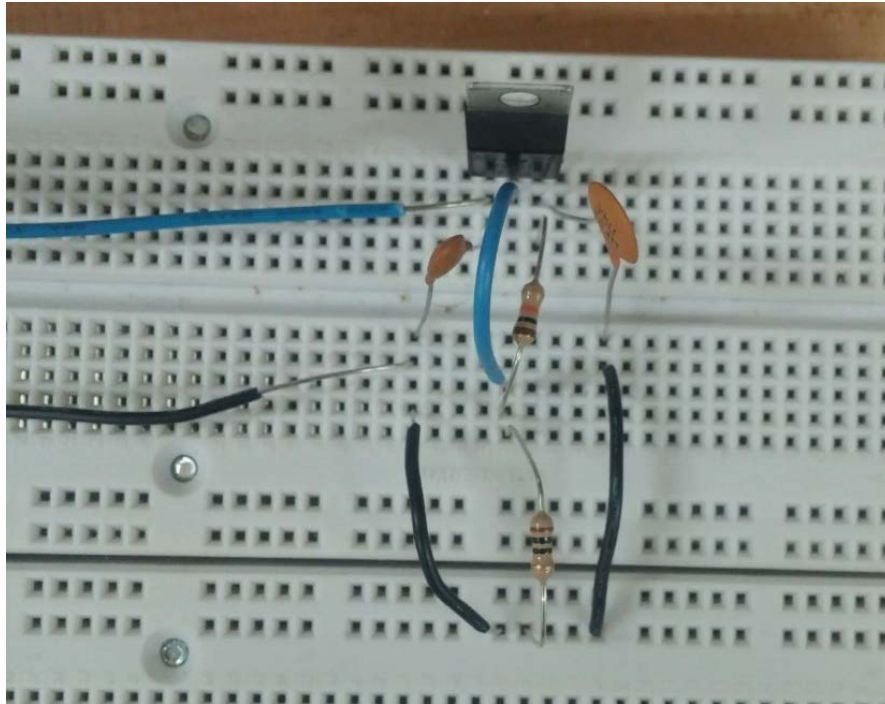
Figure 35 Picture taken of physical circuit built on breadboard with LM7805 regulator [139]

The blue wire on the left is the 12 volt DC power supply, the black wire on the left is the connecting ground wire to the power supply. The output voltage was measured to be 5.03 volts when a 1k ohm resistor was used for R1 and a 10 ohm resistor used for R2. These resistors values are different than the ones calculated for the LT1085 because this is a different regulator.

6.2 Initial Software Implementation

The software development component of the project will be comprised of two subsystems. The first subsystem will be the software infrastructure to program the Raspberry Pi. The second subsystem will be the Android mobile application. These two subsystems will be developed and tested simultaneously in order to stay on track with our project milestones. The programming languages being used in this project will be Python for programming the microcontroller units and Java for programming the mobile application. The development and implementation process will follow the created development design plans that are explained in detail in sections 6.2.1.2 for the Raspberry Pi and 6.2.2.2 for the Mobile Application.

Both systems will go through extensive testing procedures that are explained in detail in section 7.4. After both systems have been successfully built and tested, they will be integrated and undergo System Testing and validation in order to make sure that the System is fully functional and satisfy the requirements set during the planning stage of the project. The following sections will explain in detail the

software requirements needed to build the Automated Vehicle Anti-Theft Security System.

6.2.1 Raspberry Pi

The Raspberry Pi needs an Operating System, Raspbian, to be installed. This OS will be stored in the SD Card. Once the OS is installed. The development phase of programming the communication between the storage, camera and sensors can begin.

The software used to program the Raspberry Pi will be written in Python, a programming language supported by the Raspberry Pi. The use of python gives the developers an advantage because all the members have seen Python and it is a very easy to understand and read language. The team members can focus on learning other technologies for the system such as video streaming using Python and the Raspberry Pi instead of spending the time learning about the basic concepts and syntax of the language.

6.2.1.1 Raspberry Pi Software Requirements

The Raspberry Pi needs to satisfy certain requirements needed in order to be a successful security system. The software that will be implemented on the MCU will help satisfy those requirements. First of all, the Raspberry Pi must understand the information received by the sensors. The Raspberry Pi must be able to know what the sensor input means and act accordingly based on the sensor input. As the cameras are recording, the Raspberry Pi must process the video and send it to the Android Application. The video recorded by the camera is to be stored in the SD Card. The oldest video in the storage has to be deleted if storage space is needed. The Raspberry Pi must be able to receive signals from the mobile application to activate the speakers and change the system configurations. Finally, the microcontroller must activate the speakers and display an alert sound to scare the intruder. A step-by-step high-level flowchart to help demonstrate the logic behind the hardware and software integration components of the Raspberry Pi can be seen in Figure 6a.
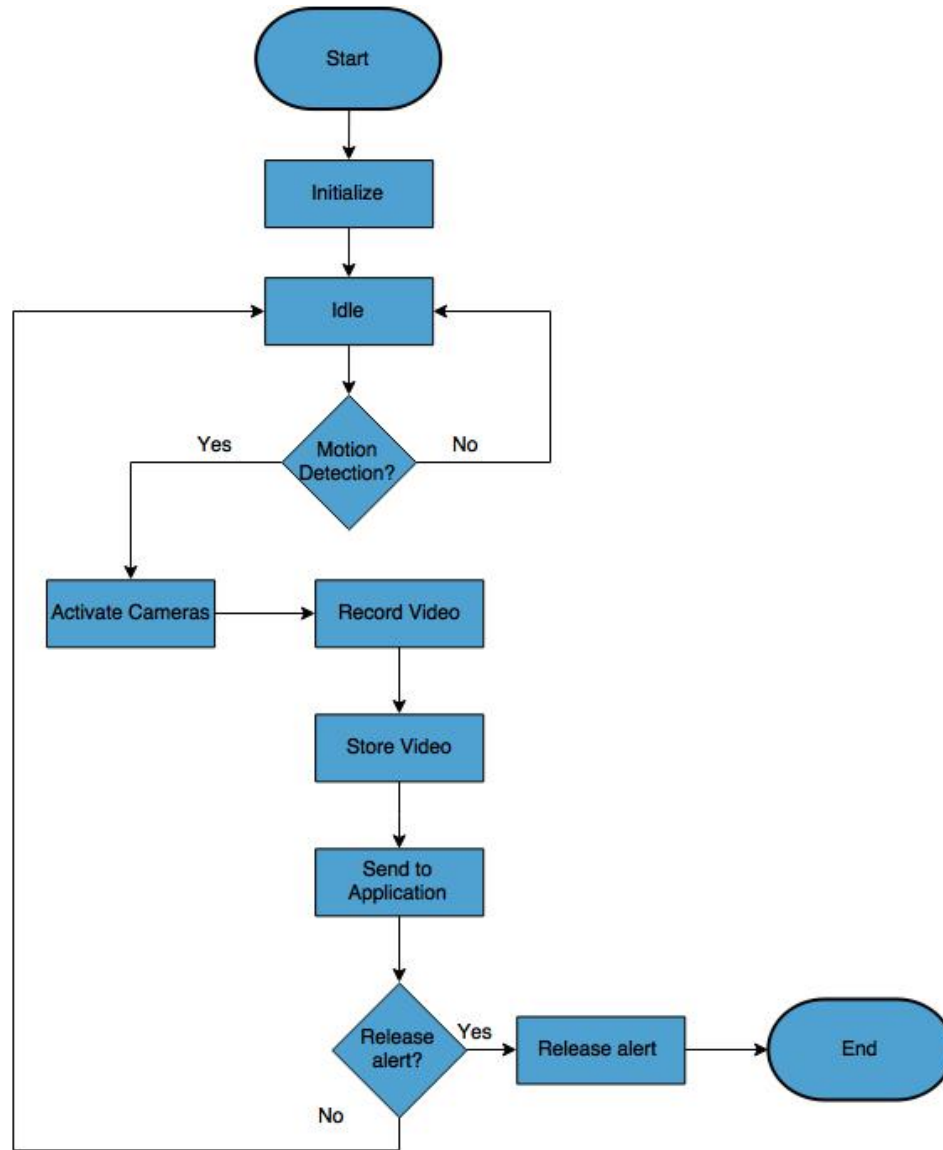
Figure 36: Flowchart depicting Raspberry Pi Software Design

6.2.1.2 Development Design Plan

The development stage of the Raspberry Pi software component will follow a specific Design plan that was created by in order to guide us and help us stay on track. The development of this subsystem will be divided in three sections. The first section will consist of designing the software necessary for each component of the subsystem e.g. sensors, speakers, and cameras. Once the software that integrates each peripheral and hardware component with the Raspberry Pi is completed, we will proceed to the integration of each module to make one subsystem. This stage consists of creating software that enables the cameras to be activated based on the sensors input. This development stage is in charge of creating the interfacing needed between components to create one fully functional

104

sub-system. Finally, the last stage of the plan is to design the communication system that will connect the Raspberry Pi to the Mobile Application. This last step will integrate both subsystems, the security system and the mobile application, to make one system. This step will focus on making sure that the application is able to understand the data sent from the Raspberry Pi such as the video stream. The Raspberry Pi has to also understand the requests made by the application and act accordingly. Each section will be subject to Unit testing and Integration Test to ensure that every module is working properly. Figure 7 below shows a high-level overview of the software design plan that will be used to program the Raspberry Pi.
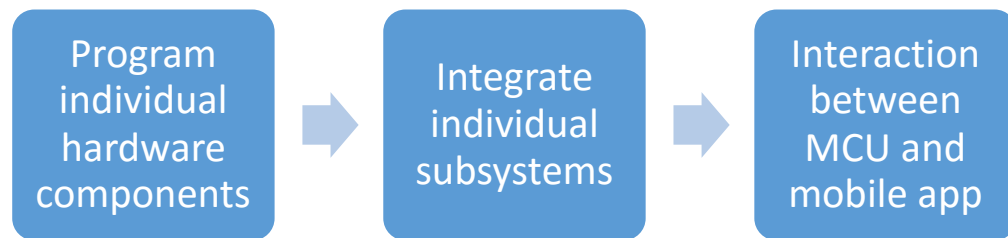

Figure 37: Design plan for Raspberry Pi software Implementation

6.2.1.3 IDE

The IDE that will be used for the Raspberry Pi software implementation stage will be IDLE. This IDE comes preinstalled with the Raspberry Pi Operating System. This is a great advantage because we do not have to waste storage on a new IDE. This IDE is a Python development environment. IDLE has two window modes, the shell window and editor window. The shell window gives the developer access to operating system services. IDLE also has a debugger tool very useful when it comes to software development. IDLE also contains smart indent and auto completion, making it easier for developers to write code in a simpler and faster way.

6.2.1.4 Libraries and Additional Tools

Several Libraries and APIs will be used in the development stage to program the Raspberry and its components. The main library that will be used is the Python Standard Library. This Library contains many tools that enable the developers to perform different operations. Additionally, the Python picamera library will be used to interface and acquire information from the cameras. Other libraries will be needed to acquire information from the sensor as well as outputting sound from the speakers.

Additional libraries and tools such as UV4L have to be installed in order to deal with the communication between the system and the application. This tool has a RESTful API available to facilitate the implementation of the streaming server in order to successfully stream video over to the Application [129].

6.2.2 Mobile Application

The mobile application that is going to be developed will be available on Android Operating Systems only. The software will be written in Java, a programming language supported by Android. The use of Java is a great advantage for the developers because all the members have had experience with Java because of previous programming courses. This allows us to spend less time getting familiarized with the syntax or some of the programming concepts and focus more on concepts and tools in which we do not have previous knowledge or experience.

6.2.2.1 Mobile Application Requirements

The Android mobile application needs to possess certain requirements in order to interface with the security system. The mobile application must have the login option available for the user to insert his/her credentials. Once the login was successful, the application must contain a user menu in which the user is able to navigate and see the different features of the application. Another software requirement is that the application must be able to support video streaming. Video will be sent from the security system and the application must be capable of displaying it to the user. The mobile application should be able to have a configurations menu that would allow the user to configure the security system. The mobile application must also have the option of sending an alert to the system in order to scare the intruder. The application must be able to have a connection with the system in order to send the users configurations and requests. A Use case diagram to map the mobile application requirements is shown in figure 9.
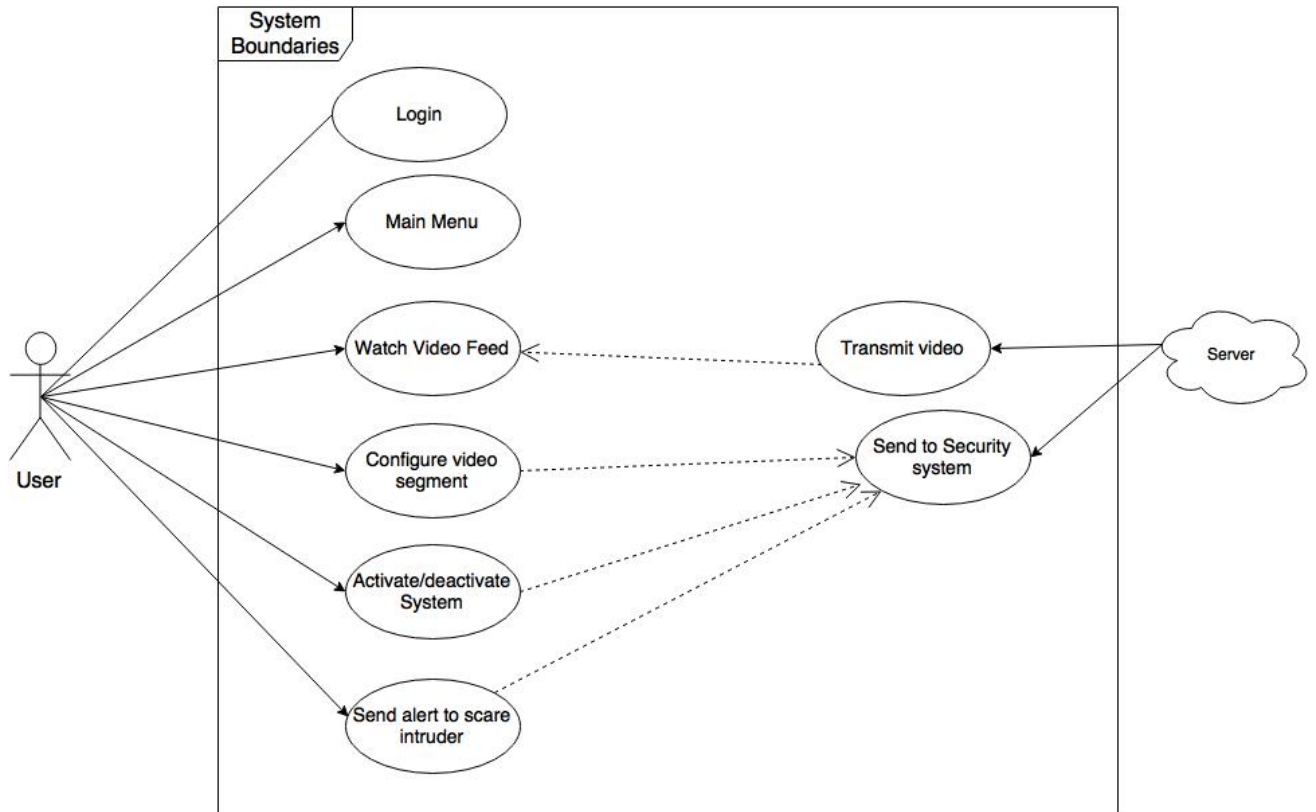
Figure 38: Use Case Diagram of mobile application

6.2.2.2 Development Design Plan

The development stage of the mobile application software component will follow a specific Design plan that was created by in order to guide us and help us stay on track. The development of this subsystem will be divided in three sections. The first section will consist of designing the user interface of the application. The login menu and main menu with all the options will be created to form the skeleton of the application. Once the layout has been created, we will start adding functionalities to the different settings, buttons and menus in stage two. This following stage will be comprised of adding functionality to the menus and buttons found in the application. This will include creating a login system for the users to register and sign in. The video playback and system configuration features will be developed in this stage.

Once the components in the Graphical User Interface have been mapped to their corresponding functionality, we will proceed to the third and last stage. Finally, the last stage of the plan is to design the communication system that will connect the Raspberry Pi to the Mobile Application. This last step will integrate both subsystems, the security system and the mobile application, to make one system. This step will focus on making sure that the application is able to understand the data sent from the Raspberry Pi such as the video stream.

The Raspberry Pi has to also understand the requests made by the application and act accordingly. This will be done by creating the Stream Server necessary to allow that connection and transmission of data. The last stage merges with the last stage of the Raspberry Pi programming design plan because the whole system will be integrated here. This causes for us to work closely with both components in order to figure out on how the can be connected and make one system.

Each section of the design plan will be subject to Unit testing and Integration Test to ensure that every module is working properly. Figure 10 below shows a high-level overview of the software design plan that will be used to create the Android Mobile Application.

Figure 39: Design plan for mobile Application software Implementation

6.2.2.3 Class Diagram

A class diagram was created to help visualize the software components that need to be implemented on the Raspberry Pi in order to successfully map the mobile application requirements. Figure 10 shows a general outline of the core classes needed to develop the mobile application. The users will have to first enter their credentials to log in. Once in the main menu, the user will have the opportunity to configure his/ her settings. The user will also have the opportunity to configure the security systems settings such as the time input for the video stream, and enabling and the system. The user will have the opportunity to watch the streamed video and be able to tell the system to send an alert through the speakers to intimidate the intruder. The server will be in charge of transmitting the data from the application to the security system.
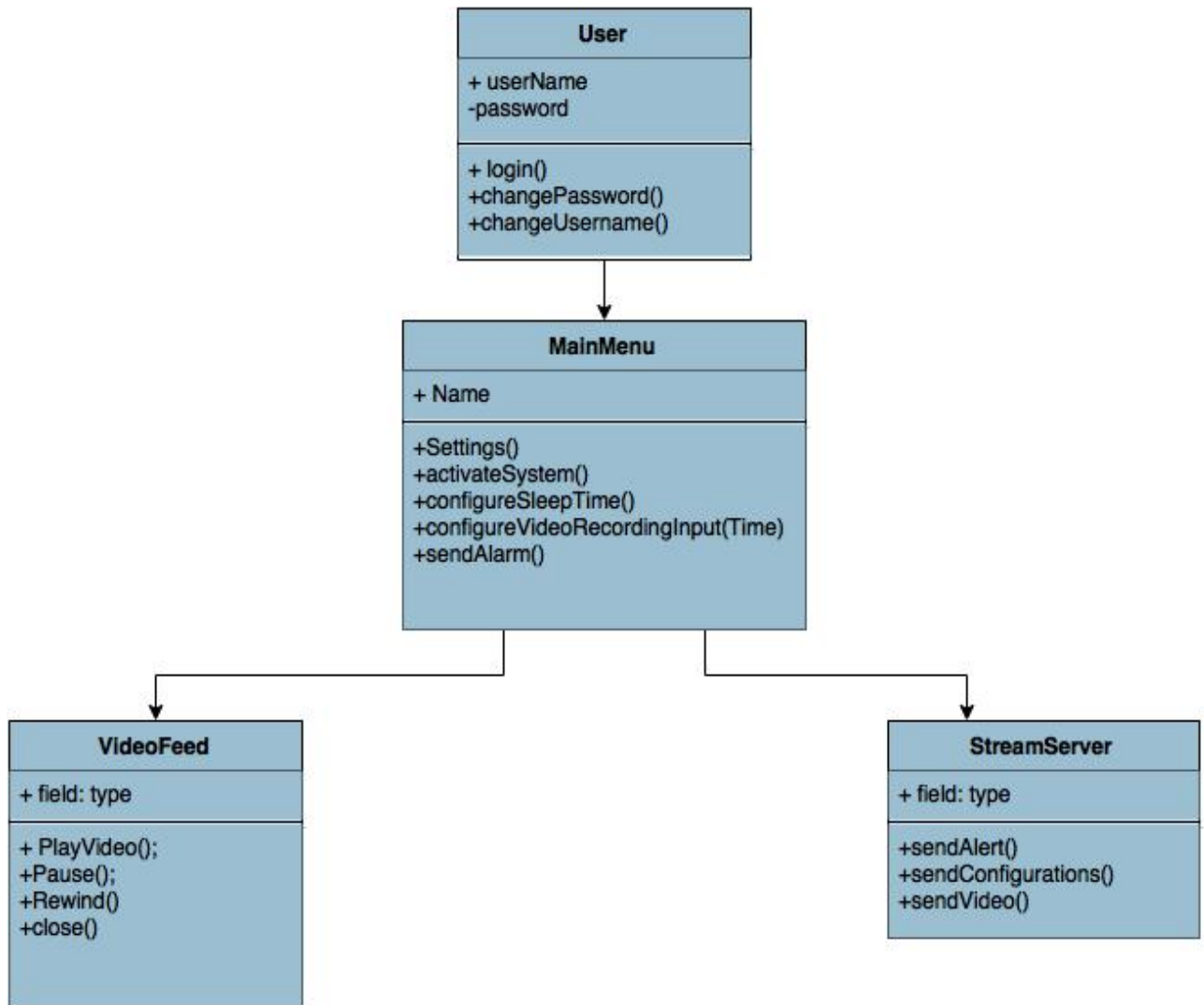
Figure 40: Class Diagram of mobile application

6.2.2.4 IDE

The Integrated Development Environment (IDE) that will be used to write code for the Android application is Android Studio. This IDE was developed specifically for the production of Android applications. Android Studio is currently the official IDE for Android development.

Android Studio contains useful features such as the user interface layout editor. This is a great tool for designing an effective, and simple user interface. It has the ability to insert buttons, text boxes, and other elements that will make the application very easy to navigate for any user that wants to access it. One of the greatest features that Android Studio has is the emulator tool. This tool is great for testing because it allows the application to run without the need of physical hardware. This give us the opportunity to test the functionality of the Graphical user interface immediately as well as allowing us to see how the application looks. This

IDE with the features mentioned above makes the ideal IDE for the mobile application development phase.

6.2.2.5 Libraries and Additional Tools

The Android Software Development Kit will be used for the implementation of this application. This SDK provides APIs and libraries needed to simplify the development. The libraries found in the SDK gives us the opportunity to create a functional and user friendly Graphical User Interface for our application. Additional APIs are being considered to facilitate the development of the login system. The API that enables the user to log in through Google+ or Facebook is a useful tool taken into consideration.

External tools such as UV4L and WebView are being considered for the development of the Stream Server. UV4L tool allows us to create a stream server for the cameras on the security system in which the video can be transmitted to the phone application. The WebView tool allows the application to enable web browser viewing from inside the application. This tool would be useful for viewing the video from a web browser in case the video is not able to be embedded in the Graphical User Interface of the application. Further APIs, libraries and tools will be researched in order to simplify the software development process [129].

6.2.3 Software Version Control

Version control is the management of changes to documents and software. In a team of developers, version control software has to be used in order to keep track of the modifications that are continually being done on the code. Version Control Software also enables the developers to work in different modules simultaneously in order to accelerate the development process.

A big part of this project consists in software development. Therefore, our team will use version control technology to keep track of the progress and oversee what each member is currently working on. The most common version control tool is GitHub. GitHub is a great tool that enables us to contribute easier in the different projects. GitHub allows flexibility because any of the developers are able to work at the pace and at the time they want because the code can be found in the repository. GitHub is also an easy tool to learn because of its great documentation. This allows us to contribute better during the implementation state and also not worrying about spending a large amount of time getting familiarized with this tool.

The use of GitHub will help us develop the software more efficiently and enabling us to have the software subsystem centralized in one place in which all the members are allowed to access without any trouble.

7.0 Project Prototype Testing

7.1 Hardware Test Environment

Our project consists of a system that is to be placed on top of a vehicle. This mean that our system will be susceptible to outside conditions. For our test environment, we will be testing that the Raspberry Pi is able to function under these conditions. We will also be testing each sensor and camera to make sure they can function properly. The light from outside can have an effect to how our cameras pick up certain pictures. The heat conditions of outdoors also can have an effect on our PIR sensors. The Raspberry Pi can overheat and malfunction if our device isn't built properly for outdoor weather. To test this, we will first test all of our parts in a lab in regular room temperature conditions. Once noting all of the parts are working and how the work, we will bring the test outside. We will make sure that the device is able to function properly on all accounts outside as well. We will make sure that our Solar Panel is working correctly outside as well.

Not only are we testing our product outside for temperature reasons, we will also be testing it atop of a vehicle. We want to make sure that our product can securely attach to a vehicle. We also want to be sure that our product can stay atop a vehicle securely while in motion. We will also be making sure that all of the parts still work after a drive. We will be testing to make sure that our solar panel is also gathering enough sunlight when attached to the top of a vehicle.

7.2 Hardware Unit Testing

Unit testing includes making sure each component will work with the same battery pack operating at the necessary voltage levels needed without overloading the components and with making sure they have enough power to operate properly. Each component that we currently have was tested and researched thoroughly. The solar charging system was tested thoroughly by first testing each piece of equipment to make sure it worked starting with the battery. The voltage across the battery was measured and was fully charged and so this was connected to the charge controller and the charge controller was then then tested by changing settings with on the LCD screen. Then the solar panel was connected and was verified to produce voltage and current and charge the battery properly. After the system worked like expected, a load of a 1000-ohm resistor was connected to the outputs of the charge controller and had proper current running through it verifying our results.

Next, the Raspberry Pi module was briefly tested for general functionality:

- With power connection and SD card with Raspbian installed, verified that it booted correctly and displayed the desktop screen. Verified that the terminal and filesystem responded as expected.
- Verified that running the microcontroller with power, and unplugging, would not cause adverse effects to the electronics.
- Verified the voltage requirements were 2.5A and 5V.

7.3 Software Test Environment

The test environment with respect to the software implementation portion of the project will primarily involve the software code for the Android application, and the embedded code for the Raspberry Pi function. For the Android application we will try to keep the test environment very general to restrict future use as little as possible. The Raspberry Pi cluster will be tested on a much closer and more limited scale as there will be no large variation of hardware involved between uses.

Android Application

The test environment will consist of a mobile device running Android version 5.0 (*Lollipop* released November, 2014) or later. This is to setup a baseline of performance with respect to how the product may be used during development and by any other possible user. Using a valid Android device, we will verify that all of the outlined system specifications are met within accepted ranges. As well, we will verify that the software functions smoothly and does not result in any disruption of service. Some overarching core guidelines for the Android system software testing are as follows:

- Efficient initialization and exiting of application with respect to memory management and persistent data fields.
- Responsive and intuitive GUI elements.
- Predictable and reliable communication with the security device, handling edge and failure cases such as network failure appropriately.

Raspberry Pi Cluster

For the Raspberry Pi Cluster, the environment will consist of just that. The following core components will be present during the Raspberry Pi software unit testing final test runs:

- 4x Raspberry Pi 3 Model B
- 4x Micro SD Card Storage Devices
- 4x Raspberry Pi Camera Module V2
- 1x Ethernet Switch
- 1x GSM Module

Additionally, software tests will be run on the onboard operating system on the Raspberry Pi, Raspbian.

7.4 Software Testing

The software testing effort will be comprised of several phases. All of the members will participate in the testing phase to ensure the overall functionality of the Automated Vehicle Anti-Theft Security System. The next sections describe the testing procedures that will be applied to the Raspberry Pi and Android Application

software components of the system. Figure 7 below shows in a high-level the Software Testing Approach that will be used to test the system.
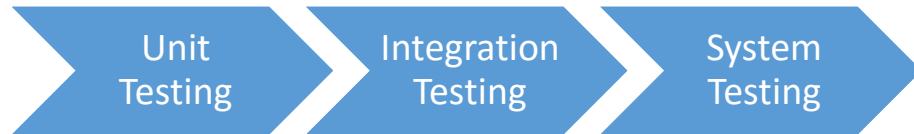

Figure 41: Software Testing Phases

7.4.1 Raspberry Pi Software Testing

The testing of the Raspberry Pi Software component will be done in three phases. The first phase consists of Unit testing. Individual test cases will be created for each subsystem to test their functionality. These test cases will be executed in order to make sure that the Raspberry PI is able to interface well with the different parts attached such as the speakers, sensors, SD Card and Storage. Unit testing of each peripheral will help the developers see if the Raspberry Pi is able to perform necessary tasks such as reading data from the sensors when they are activated. As well as making sure that the cameras are able to record video and store it on the local drive. This Unit testing phases helps the developers discover the minor logic errors that may have been accidentally created in the software Implementation stage. By only testing one specific module at a time, the developers are able to focus on the source code related to that subsystem and make sure that it can work properly.

After each subsystem is working properly, and all the peripherals attached to the Raspberry Pi have been tested, we shall proceed to the Integration phase of the Raspberry Pi Software testing. This phase of the testing effort consists of being able to integrate the different modules of the security system and test the functionality of the Raspberry Pi Software implementation as a whole. One example of this phase is testing the ability of the Raspberry Pi to record video from the camera when the sensors tell the Pi to do so. The Pi can then proceed to prepare the video stream that needs to be sent to the mobile application. Integration testing enables the developers to test and see that the different software components can communicate well between each other. This testing helps finding the weaknesses and bugs in the system that prevent seamless communication and interaction between the modules of the subsystem. Unit testing makes sure that the individual components of the system are functional individually. Integration testing makes sure that the behaviors and actions taken by other modules of the same subsystem do not affect the functionality of the other subcomponents.

The integration testing phase is completed when each of the components of the subsystem are able to work and communicate together as a whole. After the completion of the second phase, the system will go through the third and las testing phase, system testing. This last phase will consist of integrating the physical security system with the Android Mobile Application to create the Automated Vehicle Anti-Theft Security System.

7.4.2 Android Application Testing

The Android Mobile Application will follow a similar testing process as the Raspberry Pi software component. The unit tests and integration tests of the application will be done in the Android Studio Environment using the emulator tool to simulate the hardware devices. The emulator tool simulates an Android device in order to facilitate the testing process of the application. Once the test cases are passed, testing will be done on a physical Android device.

The application will go through different unit tests to see its functionality. Functionality includes testing the buttons, menus and options to make sure that they are able to respond correctly before sending any information to the Raspberry Pi. Unit testing will ensure that the application can transmit video and have the infrastructure necessary to communicate with the security system. Phase one of the mobile application testing will help ensure that the modules of the application are created properly and fully functional before integrating subcomponents and communicating with the Raspberry Pi. Once this phase is complete, we will proceed to integrate the modules of the application and perform further testing.

The phase two of the mobile application testing will be integration testing. In this section, each module of the application will be integrated to make sure that each subsystem works and communicates with the other. This testing methodology will help us find any bugs in the application that need to be fixed before launching the application for System Testing. After the application is put together and passes the integration tests, the application will go through several usability tests to ensure that the application is user friendly.

 Usability testing will consist of first testing the application as if we were the users and be able to see if the Graphical User Interface is user friendly. The second part of the usability test is launching the application and receiving feedback from other participants about the application and how simple it is to use. The results and feedback acquired from the usability tests will help us further improve the application and its simplicity.

After both subsystems, the application and the Raspberry Pi have gone through extensive Unit and integration tests, the system will go through its last testing phase. System Testing.

7.4.3 System Testing

The last phase of testing will consist of making sure that the Raspberry Pi and security system are fully integrated with the Android mobile application. This phase will test the communication between the Raspberry Pi with the GSM module and

the Android application of the user. This will make sure that a connection between the Pi and the mobile application is established and the video can be transmitted in order to be viewed by the user in the application. Any problems regarding the media encoding and video transmitting will be found here and will be patched to create that seamless experience. The configurations to the Raspberry Pi that would be done in the application will also be tested in this phase. This section will help the developers make sure that the data that was sent from the application is received by the security system and the data sent by the system is received by the Android application to be displayed.

Once the System test has been done and the security system has been fully integrated, further usability testing will be done to make sure that the users are able to use the application without any difficulty. The system will go through a validation process to ensure that it satisfies the requirements that were specified in the planning stage in the beginning of the semester.

8.0 Administrative Content

8.1 Finance and Budget

The Automated Vehicle Anti-Theft Security System is a Senior Design Project developed by Computer Engineers and Electrical Engineers. This system is comprised of software and hardware components. The software aspect of the project does not come with any monetary cost due to the fact that the software development and implementation needed for this system to work is free due to the fact that all software that it is to be used to build the security system has a free license.

However, there are hardware components needed to make this system work. These products have a cost. The total cost will consist of the PCB, Microcontroller, power supply components, storage device, cameras, sensors, communication modules and the construction of the Chassis. The project is not funded by any company or organization. The cost of all materials will be covered by the individual team members. Therefore, a list of all components used to build the system with their respective cost was created in order to keep track of the parts used and to equally divide the total cost equally among the members. The list of components is found in *Table 1* below.

Description	Quantity	Price per Unit	Total Price
Motion Sensors	4	$2.50	$10.00
IMU	1	$25.00	$25.00
Solar Panels	1	$179.99	$179.99
Solar Panel Battery	1	$26.99	$26.99
Charge Controller	1	$14.65	$14.65
Security Cameras	4	$24.99	$99.96
GSM Module	1	$19.95	$19.95
PCB	1	$60.00	$60.00
Raspberry Pi 3 Model B	4	$35.69	$142.76
Samsung EVO+ 32GB	4	$13.73	$54.92
Speakers	1	$18.53	$18.53
TOTAL			$652.75

Table 10: Cost Table

8.2 House of Quality Trade-Off

Marketing Requirements			Engineering Requirements					
			Wireless	Camera Resolution	Solar Energy	Cost	Dimensions	Motion Sensors
			+	+	+	-	-	+
	1) Ease of Management	+	↑↑			↓	↓↓	
	2) Accuracy	+	↑	↑↑				↑↑
	3) Video Quality	+		↑↑		↓↓		
	4) Durability	+			↑↑	↓		
	5) Cost	-	↓	↓↓	↑	↑↑	↓	↓
	6) Portability	+			↓		↑↑	
	Engineering Requirements Target		>5 meters	>480p	<200 watts	<$1000	0-1.5× 0-1.5× 0-1.5 meters	< 2 meters

Table 11: House of Quality

The diagram above shows how the engineering requirements compare to the Marketing Requirements. This table is used to discover the trade-offs that are considered when an important decision regarding to the product design has to be made. In the engineering requirements we considered the top six critical components of our system. On the left, the Marketing Requirements are the critical features that are used to sell a product. The table inside depicts the correlation that the engineering requirement and the marketing requirement as. A ↑ means there is a positive correlation. A ↓ means a negative correlation. The more arrows there is the stronger the correlation. When it comes to product development this helps the engineers and developers see what are some of the trade-offs of having certain features or buying certain components.

8.3 Milestones

FALL 2016	
Description	Dates
Senior Design 1 Project idea	August 23-August 26
Discussion of Roles	August 27
Writing Documentation	August 29-September 8
Initial Project	September 9
Research	September 12-October 1
Writing Draft for Table of Contents	October 1-October 30
Table of Contents	November 4
Individual Writing and research	November 5-10
Draft Document	November 11
Designing Prototype	November 12-20
Purchase Components	November 21
Filling in Documentation	November 21-28
Last checks and review	November 28-December 5
Final Senior Design 1 Document	December 6

Table 12. Fall Milestones

SPRING 2017	
Description	Dates
Build prototype	TBD
CDR Presentation	TBD
Test Prototype	TBD
Conference paper	TBD
Middle Term Demo	TBD
Finalize Project	TBD
Final Demo and Presentation	TBD

Table 13. Spring Milestones

8.4 Roles of Responsibilities

In our group, we have 4 members: two Computer Engineers and two Electrical Engineers. The focus of the EE students will be on the lower-level electronics and power systems of the device, most notably the microcontroller, PCB construction, and solar panel power distribution. The CpE students' focus will be on the higher-level software code, mobile communication, as well as the device's data storage. Both roles will be involved in the microcontroller system design. While these are the main designated roles, we can take advantage of cross-communication and assistance between these interconnected modules in the purpose of efficient design, implementation, and testing of our project. The diagram below outlines the rough distribution of tasks.
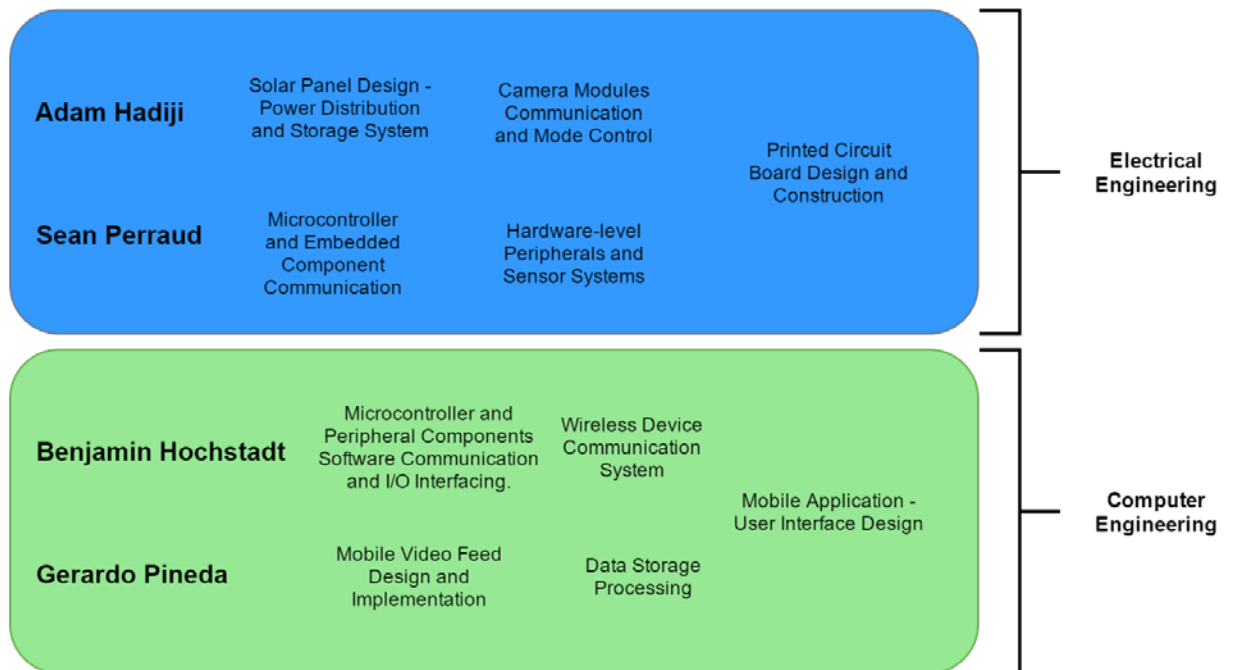
Figure 42. Distribution of Tasks

There is a large emphasis on providing support between modules even across the two disciplines. Within the degrees of Computer Engineering and Electrical Engineering there is overlap in concepts learned and experience gained both in and outside of the classroom. The primary responsibilities are listed above but by no means are those restrictions placed upon group members. Both professional experience and personal interest can allow mobility in the paths towards project completion.

There exists an inherent advantage in being actively acquainted with the opposite subject area present in our project. An electrical perspective that has knowledge of the software systems and interfaces required, and a computer perspective that understands the system's power needs and the capabilities of the hardware present are both able to achieve their goals in a much more efficient and elegant manner.

8.5 Acquired Components

Shown below are our acquired components thus far in the development process.

Figure 43. Micro SD Card

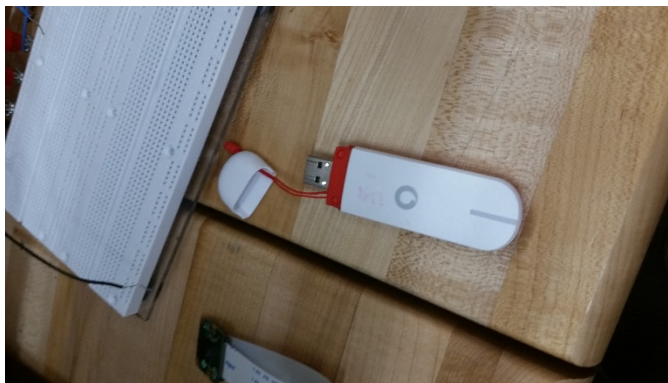*Figure 44. Raspberry Pi 3 Model B*

Figure 45. PIR Sensors

Figure 46. GSM USB Module

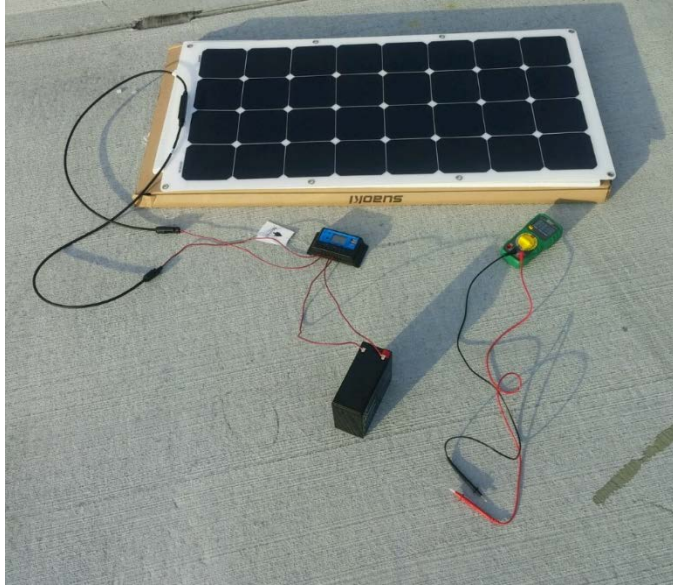
Figure 47. Camera Module

Figure 48. Speakers

Figure 49. Solar Charging System

9.0 Conclusion

The extensive research and design done throughout this semester, found in the documentation above, has given us a great learning experience in the field of Computer and Electrical Engineering. At the beginning of Senior Design 1 the team was without direction. We entered this class without any idea of what would our project would be. We had to brainstorm and analyze about ten different ideas and see which idea could be the right one. After analyzing about ten different ideas, we finally chose what will be a two semester project that we will see follow through from the early stages of proposals all the way to final product delivery and demonstration. The Automated Vehicle Anti-Theft Security System has the perfect combination of hardware and software components that provides each team member with enough diversity to learn and work with both. The Automated Vehicle Anti-Theft Security System will challenge us to apply all the knowledge learned in school and previous work experiences. This project will give us a great preparation for what is to come after graduation.

Once the idea was selected, we as a team began to research about similar systems and brainstorm of additional features that set this system apart. After finding those unique features, our motivation for this project increased. We wanted to implement a system that could help civilians and help prevent crime. We were convinced that this was going to be a great project.

We started the research process to see what components could be used to create this system. We had to deliver a ten-page proposal and this was the initial step to writing the 120+ pages research paper. We drafted a list of requirements and functionalities for the system in order to divide the work and let every member of the team focus in a specific section.

A table of contents was created to be used as a guide. This table of contents allowed us to map the different components and sections that need to be discussed. Once the table was created, we were able to divide the work and branch out to do the research. Weekly meetings were done to monitor the progress.

Once each member had their section assigned, each one began the process of researching both software and hardware components necessary for the implementation of the system. This extensive research document is the result of dedication and hard work. This is the culmination of the research and design to develop a security system. These designs have yet to be implemented. The group's goal for Senior Design II is to finish purchasing the devices and components that are missing and begin the design, prototype, test phase of the project.

Another of the team main goals next semester is to get an even better learning experience than this semester. This semester we were able to learn things that were never mentioned in any classes. Schematic and PCB design skills as well Software design planning, and technical writing skills were some of the skills that we have learned this semester. Time management, organizational and teamwork skills were also developed this semester. These soft skills are also very important

for our development as engineers and this is a great way to put those skills into practice.

We are pleased to have completed our design document. We ready to start building, prototyping and testing our project. We are ready to create the Automated Vehicle Anti-Theft Security System.

Appendices

Appendix A – Copyright Permissions

Permission to use an image.

CS   CircuitsToday Store <info@circuitstoday.com>
Tue 11/8, 4:14 AM
Sean Perraud ⌄

Hi Sean,

Permission granted for use as desbribed in mail.

regards,
Jojo Joson
Editor
CircuitsToday

SP   Sean Perraud
Dear Circuits Today,   My name is Sean Perraud and I am in a Senior Design 1 (EEL 4914) class at the University of Central Florida. In the class I am doing a project dealing with a car security system.

Permission to use an image.

PB   Paul Bourke <paul.bourke@gmail.com>
Sun 11/6, 7:04 PM
Sean Perraud ⌄

Sure, permission granted.

SP   Sean Perraud
Dear Paul Bourke,   My name is Sean Perraud and I am in a Senior Design 1 (EEL 4914) class at the University of Central Florida. In the class I am doing a project dealing with a car security system.   I'...

Permission to use an image.   ⌃

M   matthawkinsuk@gmail.com on behalf of RaspberryPiSpy <info@raspberrypi-spy.co.uk>   👍   ↩ Reply all | ⌄
Thu 12/1, 6:40 PM
Sean Perraud ⌄

Hi Sean,

Feel free to use the image as described in your email.

Thanks for asking and good luck with your project.

Regards,

Matt

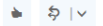**SP**   Sean Perraud
Dear Raspberrypi-Spy,   My name is Sean Perraud and I am in a Senior Design 1 (EEL 4914) class at the University of Central Florida. In the class I am doing a project dealing with a car security syste...   Wed 11/30, 4:40 PM

Permission to use image

Adam Hadiji
Thu 12/1, 8:11 PM
sknoth@linear.com

Sent Items

Hello,

My name is Adam Hadiji and I am currently a student at the University of Central Florida and I am writing a Capstone report for my school. I would like to ask for permission to use an image from the LT1085 datasheet at: http://cds.linear.com/docs/en/datasheet/108345fh.pdf
I would like to use the Pin Configuration Image. I will properly reference any image and information used if that is okay.

Thanks,

Adam Hadiji

Contact Id: A2XEU39C34IEDT

Adam Hadiji
Thu 12/1, 1:04 AM
productadvertisingapi@amazon.com

Hello, I want to give more detail on the following message:

Contact Id: A2XEU39C34IEDT

Your e-mail address (required): ahadiji@knights.ucf.edu

Primary E-mail Address (associated with Associates account):

Associate ID:

Errors (if any):

Please provide a brief description of caller's inquiry (required): customer asking an authorization for project purposes that he ordered already for Suaoki 100W 18V 12V Solar Panel Charger SunPower Cell Ultra Thin Flexible with MC4 Connector Charging for RV Boat Cabin Tent Car(Compatibility with 18 (Lawn & Garden) by SUAOKI and Mohoo 20A Charge Controller Solar Charge Regulator Intelligent USB Port Display 12V-24V by MOHOO

For better clarification: I am asking for written permission to use the main product image for the Mohoo 20A charge Controller Solar Charge Regulator Intelligent USB Port Display 12V-24V by MOHOO. I am asking for this permission so I can use the image in a school Capstone report (Educational purposes). I am currently a student at the University of Central Florida.

Thank you,

Adam Hadiji

Usage of Image

Adam Hadiji
Thu 12/1, 7:27 PM
news@altenergymag.com; bobh@ljbmanagement.com

Hello,

I am currently a student at the University of Central Florida and I would like to ask for permission to use the following image for a Capstone Report for educational purposes:

Figure 7: Capacity vs. Discharge Rate
From the website: http://www.altenergymag.com/content.php?post_type=1884
Please let me know who I need to contact to get permission to use this figure.

Thanks,

Adam Hadiji

Appendix B – Datasheets

LM7805 datasheet:

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LT1085 datasheet:

"7.5A, 5A, 3A Low Dropout Positive Adjustable Regulators," [Online]. Available: http://cds.linear.com/docs/en/datasheet/108345fh.pdf. [Accessed 29 November 2016].

Raspberry Pi datasheet:

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