Signal Operated Lock And Security (SOLAS) system

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***Abstract* — Home security is an ever-present concern. With the SOLAS system, home entry is made more secure using RFID, gesture passwords, and camera images. The system is also easier to use and more accessible than using a physical key. To open the door, the user must possess one of 4 accepted RFID tags and input a customizable gesture password. A camera also uploads pictures of any movement to a website where the user can monitor activity by the door. If a user is more concerned with accessibility over security, the gesture password can be turned off through the website.**

***Index Terms* — Access control, camera, gesture recognition, infrared sensors, microcontrollers, RFID tag, security.**

I. Introduction

One of the daily hassles of life is trying to unlock and open the front door when already carrying your items from the day. It might be groceries from the store, laptop and books from work, school project, or some boxes while moving. No matter what the items are, opening the door while trying to manage all the other items can result in dropping something; and after a long day, that just makes a frustrating task even more frustrating.

Our project, the Signal Operated Lock And Security system, or SOLAS, strives to eliminate this frustration. Arriving home should be the time of relaxation after a long day of hard work. The main goal of this project is to introduce an easier way to open the door. With regular house doors, as you walk up to the door carrying items in both hands, you must shuffle everything to one hand while you fish keys out of your pocket, and you end up losing everything else in the pocket, then holding everything awkwardly while you use the key to unlock and open the door. The SOLAS system reduces the need for a physical key almost entirely, instead using RFID as its "key". Each user will wear a light bracelet embedded with an RFID tag. Whenever they come near enough to the door, the system automatically detects the RFID, then only requiring the user to input their gesture password. This reduces the need to unlock the door with a physical key, although the door lock will still have a keyhole in case the battery dies. This however will not happen after at least a year, so the user has to replace the system's battery only occasionally and thus still never have to use a key.

A door lock system would not be complete without added security though, and the SOLAS system has several security features for the user. The first feature is the gesture controller to be used inside of the lock system. When the user approaches the door, the system first checks if any accepted RFID tag is in the vicinity. If there is, a gesture controller then reads in hand movements from the user which act as a passcode to unlock the door. If accepted, the door then unlocks for the user. The gesture password of the door lock is completely customizable by the user. If they prefer more security, they can program the gesture controller to take a long series of gestures before unlocking the door. If the user is more concerned with accessibility, they can program the gesture controller to take a very simple password that can be input even while carrying many items. For example, the password could be moving a hand towards the left in front of the controller, then back to the right, requiring hardly any effort from the user. If desired, the user can disable this feature entirely, and the RFID system still provides sufficient security.

Another feature the SOLAS system has is a camera linked to a website to monitor the use of the lock and any activity in the porch area around the lock. The SOLAS system comes equipped with a short-range proximity sensor which detects movement, notifying the rest of the system when it does. Whenever movement is detected, the camera takes a picture and post it to a website that the user can login to. Not only does this allow the user to monitor who is approaching their house, but also deters any package delivery theft, and conveniently provides evidence in case it does happen. In the event that someone approaches the door, an acceptable RFID tag is sensed, but the gesture controller reads in an incorrect password, a picture is taken, and when posted to the website it is red flagged. This allows the user to scrutinize this picture more carefully and ensure that it was only an accidental incorrect password and not perhaps a stolen bracelet with an intruder attempting to gain entry.

II. Research

In order to gain more knowledge on the subject, research was done into the underlying technologies needed to construct the SOLAS system, including RFID and gesture controllers. This was so the team could select parts best suited for the goals of the project.

A. ESP32 Microcontroller

There were a few things to consider when choosing a microcontroller that met the specifications for SOLAS.

Mainly, power consumption should be kept low while still being able to support the variety of sensors, motor, and other modules. The microcontroller has to be able to accomplish all these and be reasonably priced.

It was difficult making the tradeoffs to get as close to an ideal microcontroller for this project as possible. The ideal microcontroller choice for SOLAS is the ESP32-WROOM-32. Although overall current consumption is high, this is a necessary trade off as the ESP32 offers integrated Wi-Fi required for web access. This integration of Wi-Fi and other peripherals increase overall power consumption for the device, but there are adjustments that can be made to reduce this. Overall, the ESP-WROOM packs many advanced features into a single powerful chip providing a solution that does not take up much space on a printed circuit board.

B. Radio Frequency Identification (RFID)

For the SOLAS system to be secure, it was decided to use RFID as one of the “keys” to the door. Each user of the door lock or resident of the house will wear a bracelet that has an RFID chip in it corresponding to that specific door lock. Using this technology, user bracelet tags can be identified, analyzed, and in our case, either approved or denied without any effort from the user.

The RFID system consists of an RFID tag and antenna in the object to be identified, as well as the RFID reader module. The RFID reader sends out radio waves requesting data from the RFID tag. The RFID tag sends identifying data back through radio waves which the reader stores and interprets [4]. The data collected by the reader is then further analyzed by a host system which will either approve or reject the tag.

The RFID tag itself can be passive or active. The passive form has the chip, antenna, and substrate. The chip contains all the necessary data and can be read-only, write-once and read-many, or read-write. The antenna is responsible for absorbing the radio waves from the RFID reader, and then sending its own data back. This antenna uses the energy from the reader’s radio waves to send back its own data, thus not requiring any energy supply. Larger antennas can receive and send data from a longer range while the smaller antennae have a shorter range. The low-high frequency antennae have a coil shape due to these frequencies having magnetic properties, while ultrahigh-frequency antennae or more cylindrical in shape due to the electrical properties of those frequencies. The low-high frequency spectrum is used with the passive tags while active tags and antennae use the UHF side of the spectrum. Finally, the substrate holds these pieces in place on the tag, popularly made of mylar or plastic.

Active RFID tags contain the same 3 components as passive tags as well as power supply and onboard electronics. The power supply enables the tag to constantly send out a signal, as well as allow it to reach a further range than the passive tags. The onboard electronics differ from product to product, mainly including sensors or processors to read in and analyze local variables depending on the purpose of the product.

The type of RFID tag chosen for the SOLAS project was the passive tag. The main reason was so that the bracelet worn by the user could be small and lightweight, since no additional power supply and electronics would be needed. With no power supply, the user also doesn’t need to change the batteries in the bracelet. Another reason is the security factor, since active RFID tags constantly send out a signal, that signal can be “spoofed” and mimicked by a malicious user later.

C. Gesture Controller

For increased security of SOLAS its design includes the capability to detect specific hand gestures made by a user. A specific set of hand gestures acts as a password for unlocking the door. This gesture system is achieved through IR-based sensors. The components required for this to work include an infrared light-emitting diode (IR LED) and four directional photodiodes.

The IR LED emits infrared light at a specific distance and when a hand is in range of it the infrared emitted bounces back. This bouncing of the infrared is detected by the photodiodes and helps determine the direction of the gestures from the different intensities of the reflected infrared that is received by each photodiode. These photodiodes are positioned to detect up, down, left, and right directions [2].

Fig. 1 and Fig. 2 below how the gesture controller detects and interprets directional movement. The LED at the lower portion of the sensor system in Fig. 2 emits light which reflects off close objects towards the upper photodiodes. This only shows current location however, the chart in Fig. 1 illustrates how taking the location over time shows movement in a certain direction. As one photodiode receives more light than less light over time, it is interpreted that an object just passed over that photodiode [2]. Overlaying all 4 diode time charts results in 1 gesture, since it can be seen which photodiode first “saw” the object, and which saw it last.

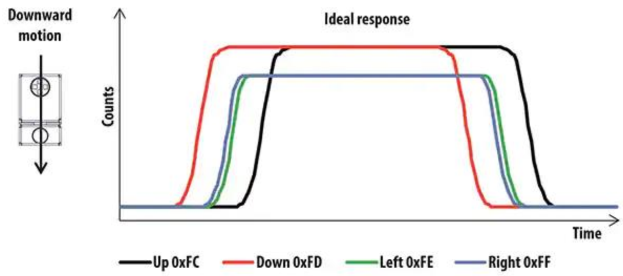


Fig. 1 Broadcom gesture controller response graph

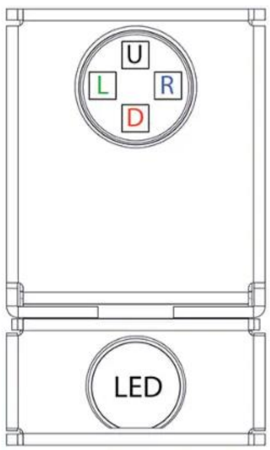


Fig. 2 Broadcom gesture controller photodiode layout

D. Camera

SOLAS uses a camera module to take images in front of the door activated by motion sensors. These images are then be uploaded to the SOLAS website for the user to look at. A camera module consists of four components, a lens, image sensor, a printed circuit board (PCB), and an interface.

An image sensor according to the AN5020 Application note is an analog device that converts the light it receives into electronic signals to form an image and the two types of image sensors that can be used in digital cameras are charge coupled device (CCD) sensors and complementary metal oxide semiconductor (CMOS) sensors [3]. A lens is necessary to focus the light onto the image sensor to help capture whatever it is pointed at. The camera module interface will allow for a connection to the microcontroller. In the AN5020 Application note the main signals transferred between a camera and a microcontroller through parallel or serial interfaces are control signals, image data signals, power supply signals, and camera configuration signals. The control signals control the transfer of data through clock synchronization. Image data signals deal with the transfer of each image data bit to the microcontroller. Power supply signals power the camera module provided by the microcontroller and the configuration signals set the resolution and other image features.

The ideal camera chosen for SOLAS is the ESP32-CAM. At such a low price point, it offers many features such as a processor, Bluetooth, and Wi-Fi. Since power consumption is high, techniques to limit it are be utilized such as turning on the camera only when needed.

III. CONSTRAINTS

A. Economic and time constraints

The economic and time constraints play a major role in the design of SOLAS. The funding for this project was provided entirely by the three members of this group. A contribution of 100 dollars from each member created a budget of 300 dollars for designing SOLAS. With this budget in mind careful consideration was taken in choosing parts that are inexpensive, but also of decent quality. Due to ordering 2 generations of PCBs, the cost totaled $360.20, only slightly more than the original budget.

Time constraints dictate the amount of time a project must be completed by or have a working prototype ready. For SOLAS, these time constraints are those imposed by the University of Central Florida. From the start of Senior Design 1 till December of 2020, time is spent focusing on the research and design of SOLAS. The implementation and prototyping of SOLAS was done in Senior Design 2. The entire period for the development of SOLAS was approximately 7-8 months to complete. A timeframe such as this means that careful consideration was made on accomplishing certain milestones to gauge the progress of the project development. The complexity of the design was also considered, since the group consists of only 3 members.

B. Ethical, Health, and Safety constraints

An ethical constraint deals with the morality of certain behaviors and actions. For SOLAS, the ethical constraints to consider would relate to the handling of the website with questions such as

"Would SOLAS collect any data on its users?" and "Are photos collected on the website accessible by the company?". These are the serious ethical issues that must be considered when designing SOLAS.

For the design of SOLAS the health of the user must also be considered. The sensors and other devices that use electromagnetic radiation in this project meet the standards for safe levels emitted.

Safety constraints consider the safety of the user. SOLAS is a system designed to be connected to the internet for its camera to function. The threat of remotely accessing the camera is a possibility that may compromise the identity and location of the user and is taken seriously in the design of SOLAS. Another consideration is the overall security of SOLAS, the possibility of spoofing the RFID tag could put the user in danger of unauthorized access. This is why the RFID tags are passive and the SOLAS system have two factors in order to unlock the system, the RFID tag and gesture-based password.

IV. Application

To setup the SOLAS system, the lock will be installed onto a door the same as a normal household door lock would be and then batteries will be placed into the back of the SOLAS system. The system will use a library called Autoconnect to help it connect to the user's Wi-Fi by providing an interface to enter Wi-Fi credentials through a smartphone. Next the user will register an account on the SOLAS website by inputting their name, email, password, and the given serial number for the SOLAS lock. Now the system is ready for use.

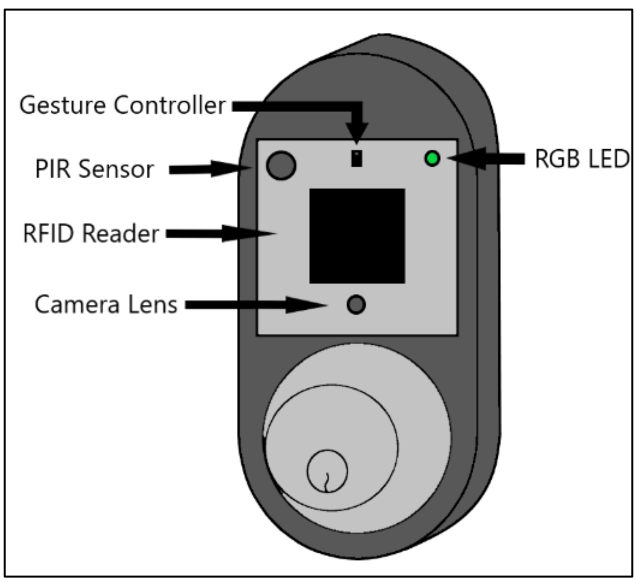


Fig. 3 SOLAS system render

A typical interaction of the SOLAS system will begin with the system in sleep mode. Once the system detects movement, the camera will take a photo and the system will turn on and indicate the activation with a blue LED. The system will then wait until the RFID reader receives an ID from the user's RFID bracelet tag for 15 seconds. If the system does not receive a RFID tag, the system will send the taken photo and go back to sleep. If the system did receive the signal, the tag ID will be compared with the one coded into the system. If they are different, the red LED turns on and the system attaches a red flag to the photo and goes to sleep. If the IDs match, the system will start the next step.

Once the RFID tag has been accepted, the system will check if the user has a gesture passcode for the lock, which they can setup using the website. If there is no passcode, the door will unlock. If there is a passcode, the door will wait till the user gives a passcode to the system. Once the gestures have been given, the system will compare it with the passcode the user made. Similar to with the RFID tag, if the codes do not match, the red LED will turn on and the photo is flagged, if they do match, the door will unlock.

The SOLAS system also includes the website, as stated before, which will allow the user to view photos from the lock and adjust the gesture passcode on the lock. The photos are displayed on the user's home page showing the most recent activity in front of the door lock. Each picture will have an indication underneath indicating whether the door opened successfully, the system read an incorrect RFID tag, the system received an incorrect gesture passcode, or if it was just movement in front of the door. If the system reads a wrong RFID tag or gesture passcode, the website will send an email to the user notifying them of the incident. Finally, the SOLAS website will include a settings page where the user can adjust the gesture passcode that would be used to unlock the door, deactivate the gesture passcode so that just the RFID tag will unlock the door, as well as associate user names to each RFID bracelet.

V. Design

With the main research done for the SOLAS smart lock, the designing phase began. The construction of the system was separated into three main sections, the hardware, the microcontroller software, and the website.

A. Hardware

The SOLAS lock system uses multiple sensors and readers to complete the functions that are specified. In order to connect all the subsystems together and to understand the data transmitted from those subsystems, the SOLAS system utilizes a microcontroller. The ESP32-WROOM microcontroller is a 48-pin component which includes thirty-nine GPIO pins. As seen in Fig. 4, the microcontroller connects to virtually every component in the system, excluding the RFID tag and the image sensor. Some of these subsystems connect to the microcontroller by using the basic GPIO pins, such as the LEDs. Other subsystems need more specific GPIO pins to transfer more sophisticated data, such as the Gesture Controller and the RFID module.

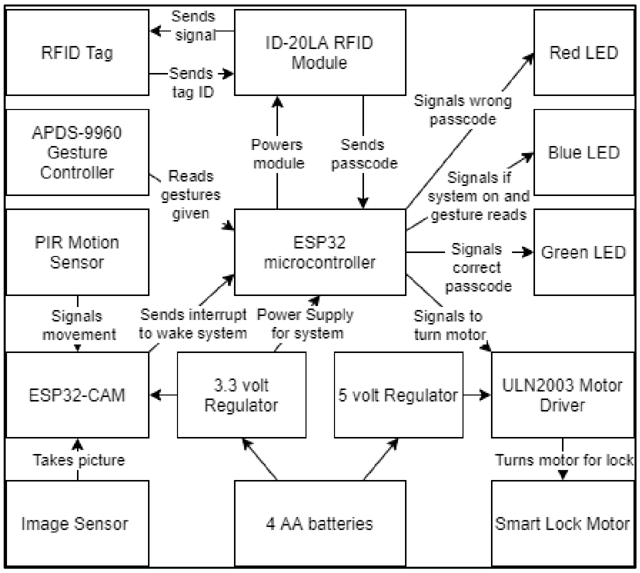


Fig. 4 Hardware block diagram of the full SOLAS system

When connecting the subsystems to the microcontroller, the design also needed to include the connections in order to supply power to the system. The Power Supply subsystem is used to supply the necessary voltage to each component. There are some components that require higher supply voltages than other components can use. For the microcontroller, the typical power supply range is 2.3 volts to 3.6 volts. To achieve this voltage, the microcontroller is connected to the 3.3-voltage regulator in the power supply subsystem. From this, other components that have this voltage within its power supply range are connected to this pin as well. As for the components that require a larger voltage, such as the lock motor driver, they are connected to the 5-voltage regulator.

Other hardware designs that are implemented into the SOLAS system include the casing in which the components will sit in and the bracelet which the RFID tag operates from. Since many of the components for the system are designed to be on the outside of the door, a casing is needed to protect the device from weather and possible break-ins. The material of this casing will need to be non-conductive as to not interfere with the RFID waves. With this in mind, we plan to use a hard-plastic electrical junction box as our outside casing. The junction box should allow the SOLAS system to fit all its components. As for the design and construction for the RFID bracelet, a set of simple rubber RFID bracelets with embedded 125kHz tags were bought for testing purposes.

B. Software

In order to incorporate the different layers of security, the software based in the door lock is orchestrated in different states. The main states are standby, waiting for bracelet communication, and waiting for correct gesture password. Each of the states and various traversals between them is accompanied by different colors of the LED in order to convey to the user what the current state is.

Before the user approaches the door, for example as they pull into the driveway, the SOLAS system is in the standby mode to saving power. As the user walks to the porch area, the proximity sensor is activated, at around 5 meters from the door. Once the proximity sensor detects movement, it wakes up more of the system, starting its search for the bracelet, and the camera takes a picture of the area which is uploaded to the website. The RFID reader sends out its request for the RFID tag to send its identification and then waits for a response. This state will continue for 15 seconds. These 15 seconds allows for a discrepancy between the time the proximity sensor senses movement and when the RFID tag comes within range. If after 15 seconds the RFID tag is not detected and the proximity sensor does not detect any movement, the whole system goes back to its standby mode to save battery.

Once the proximity sensor detects movement and bracelet is in range, the gesture controller subsystem is activated and attempts to read a password. The gesture controller is based upon receiving light bouncing off a nearby surface and converting the movement reflection into a digital signal. From here the software state can go in three ways. If the gesture controller does not read in anything that could be interpreted as a password attempt, it times out and the whole system will go back to standby mode. If the gesture controller reads in an incorrect password, the microcontroller sends a red flag to the website following the picture taken, and the system will reset to standby mode. Once a password is successfully put in, the deadbolt will unlock, and the user can enter.

All these various states and responses of the system are illustrated in a visual manner below in Fig. 5, demonstrating which actions can lead to which states and how all the states are connected to each other.

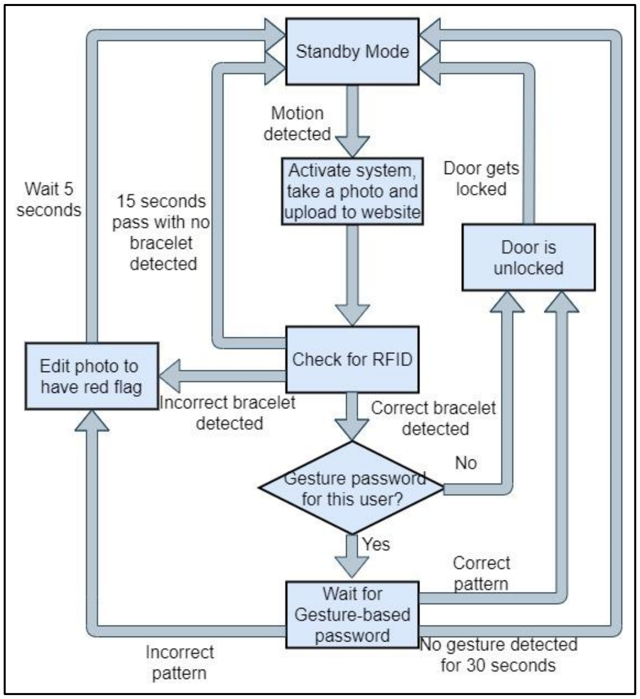


Fig. 5 Software block diagram of full SOLAS system

C. Website

The SOLAS system comes equipped with a camera, which takes pictures of the surrounding area when it detects movement, and then uploads the picture to the SOLAS website for the user to view. The specific camera is connected to only one specific account on the SOLAS website (it is possible for multiple users to be connected to one camera via the 4 RFID bracelets). Rather than attempting to have the camera login to users' accounts in some way using email and password, the camera is connected to each user via a unique serial number only the camera owner can access. When the camera posts the picture to the SOLAS website, this serial number is sent as well. When the website receives an image with such a number, the database inserts the image along with the serial number as metadata. This is the same serial number that the user will input when registering their account which they will have access to when setting up their SOLAS system.

Each image is sent with a timestamp, message, and a red flag indicator, as shown in Figure 6. The message is a short log of the event, such as if the door were opened or if there was just motion by the door. Whenever incorrect RFIDs or gesture passwords are input, a red flag is attached to the image so that when it is displayed on the website, the message displayed with the image is red. This indicates to the user that investigating the image may be necessary. Whenever such a red flag is sent, the user is also sent an email so that they are informed as soon as possible.

Fig. 6 Screenshot of website homepage

VI. Testing Results

A. RFID Bracelet

The RFID bracelet worn by the user was desired to be under 4oz, and 14-20.3cm in length, either adjustable or in various sizes in that range. The bracelet found and used is 18.85cm in length and 2.4 ounces but is not adjustable and only 1 size could be bought. This will work for the demo project, but additional sizes would need to be bought for further use.

B. RFID read distance

According to the ID-20LA RFID module's specifications, it can read RFID tags 18-25cm away. During testing, the team found that the furthest distance the RFID tag was read from was around 3.175cm. Although this distance is much shorter than 18 cm, it works for the purpose of the project. However, in future generations, a module with a further read range would be used.

C. Proximity sensor sensitivity

The motion sensor in the SOLAS system is designed to detect motion near the door and wake the system at a time appropriate for the camera to take a useful picture of the surroundings. The team decided that an ideal distance for the proximity sensor to detect distance would be around 1.2m, however the sensitivity of the sensor has not been able to be changed, and thus the system wakes up from motion up to 5.18m away. This could result in pictures taken just due to cars driving by which will not be useful to the user.

D. Battery Life

Due to the nature of the SOLAS system, the battery life of the system was designed to be at least 1 year before having to replace batteries. The battery life of the SOLAS system can be estimated using (1).

$$Battery\ Life = \frac{Battery\ Capacity\ in\ mAh}{Load\ Current\ in\ mA} \qquad (1)$$

Since we are using 4 AA batteries to power the SOLAS system, the typical capacity rating that is used is 2,500mAh. Then by using a multimeter, the load current of the system was measured to be approximately 0.275mA in sleep mode [1]. Since the system will mostly be in sleep mode, the actual battery life of the system can be estimated using this value. After completing the calculations, it was found the SOLAS system can run on sleep mode for approximately 6 months, which is half of our initial design.

E. System timeouts

Various events could happen which would leave the system powered on without having fully authorizing a user. It was planned that if motion is detected but then no further input given, or RFID tag but no gesture password, the system would return to its power saving mode after 10 seconds. An additional timeout of 30 seconds was created for when an incorrect gesture password is input to discourage attempted unauthorized entry. After testing, it was determined that due to the long range of the proximity sensor, 15 seconds was a much more suitable mid-state timeout after no RFID bracelet is detected. For locking out a user, 30 seconds was seen to be too long in the case where a user only accidentally put in an incorrect password, and the interval was decreased to 5 seconds.

F. Door unlock time

Since one of the two main features of the SOLAS system is accessibility, the team measured how fast a user could open the door as compared to a regular keylock door. The desired time was 10 seconds from movement detection to the door frame opening, the same time seen from opening a regular door. For a normal scenario with RFID and gesture-password input, the entry time was about 12.12 seconds; when the gesture password was disabled entry time was reduced to around 5 seconds. With both methods still being more accessible and secure than a normal door, having entry times near the same was an acceptable result.

G. Microcontroller software

The microcontroller software was able to be implemented with all desired functionalities. The esp32-cam captures an image and sends it to the website immediately over Wi-Fi. Meanwhile, another esp32 processes RFID, gestures, turns the door lock, and uploads information on all activity to the website. When incorrect RFID or gesture passwords are input, the image taken is tagged with a red flag to indicate suspicious activity.

The LED timing to indicate various software states mostly works as planned, with red to indicate wrong passwords, green to indicate correct passwords and entry, and blue to indicate a processing state. The only issue with the LED is that rather than the blue LED flashing each time a gesture is input, the on/off state of the LED is toggled to indicate a read. This is due to interrupts from the gesture controller and timing to the LED conflicting.

H. Website software

The user website for the SOLAS system includes all desired functionality, constructed using the MEVN stack with Nuxt.js framework. The user registers with an email, password, and camera serial number, which is used to tie them to images from the specific SOLAS system. In case the user forgets their account password, a link can be sent to the email which they can use to reset it. The home page displays all images taken, with messages about each one, including red flags on ones that may need attention. Each image has a timestamp from when it was uploaded, and the user can delete images either individually or all at once from the home page. The settings page allows the user to change or toggle their gesture password.

Along with red flagged images on the website appearing different, an alert system was integrated into the website. Whenever an image with a red flag is uploaded, the user is immediately sent an email to alert them. This way no matter where they are, they can know about suspicious activity at their house and act if necessary.

An additional feature that was incorporated is the ability to distinguish each event by user. This is done by each of the 4 RFID bracelets being marked 1-4, and when any are used to open the door, the website will not only display the picture taken, but also which bracelet was used to open the door. This also works for when incorrect gesture passwords are input; the website will display which user's bracelet was used before an incorrect gesture password was read.

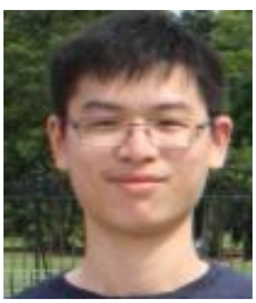
VII. Conclusion

SOLAS allows users to access their front door without the need to use a key along with the added security of a customizable gesture password, and monitors activity through a camera. Although there were some difficulties that were encountered during the integration of this project, all were solved except for the blue LED not displaying the status of the lock correctly and the large range and oversensitivity of the PIR sensor. The team believes that it has achieved creating a cheaper alternative to the existing products in the market.

BIOGRAPHY

Devon Anselmo is a Computer Engineering major. He is currently attempting to find employment as a software or systems engineer in Florida.

Matthew Guevara is currently a senior at the University of Central Florida and will be graduating with a Bachelor of Science in Electrical Engineering in May. He plans to obtain a career in the electrical engineering industry.



Keanu Zeng is currently a senior at the University of Central Florida and will be graduating with a Bachelor of Science in Computer Engineering in May. After graduating he will pursue a career in Software Engineering.

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