Semi-Truck Blind Spot Detection System

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***Abstract* — Truck Smart Blind Spot Detection System is a wireless, portable, sensor-based system that, via an LED display, alerts the driver when a vehicle or a pedestrian is occupying their blind spot. This easy to install system provides an inexpensive way to prevent accidents caused by a limited line of sight in large vehicles. The system is made portable so that it can be changed from trailer to trailer. This system is designed to work with all different models and sizes of trucks and, if implemented widely, can drastically decrease the number of truck related road crashes. This document summarizes the design and implementation of the system.**

***Index Terms* — Automotive applications, Accident prevention, Advanced driver assistance systems, Vehicle detection, Ultrasonic transducers, ZigBee, Wireless sensor networks.**

I. INTRODUCTION

The main function of this product is to increase road safety. Trucks are a big part of road hazard because an estimated 3 million commercial trucks drive on our country's roadways to move 9.2 billion tons of freight every year. According to a study published by the Federal Motor Carrier Safety and Administration, of all the truck accidents that occur each year, 20 000 of them happen due to blind spots or because a truck driver failed to adequately survey his or her surroundings. While most of the cars today come with an integrated blind spot detection system, there still isn't such a fully developed system available for trucks.

The Truck Smart Blind Spot Detection System was designed to solve this issue. The system consists of two parts: one display hub unit and three sensor units. The sensors are to be strategically placed in key locations around the outer body of the truck. The hub can be seated in the cabin in a location that is most convenient to the driver. While the system is on, the sensors will continuously send data to the LED display unit. When a sensor senses an obstruction in its region, the corresponding LED will turn on warning the driver that the region is occupied. If all the LEDs are off, it can be determined that all the areas are clear and it's safe to change lanes if needed.

One of the reasons trucks don't come with an inbuilt blind spot detection system is because the trailers hauled by truck drivers aren't constant; they frequently drop off and pick up new trailers. Truck Smart System solves this issue by providing portable sensors that be installed or uninstalled in just minutes, enabling the driver to easily transfer the sensors from the old trailer to the new trailer very quickly. All the modules in this system are connected wirelessly, eliminating the hassle of cable management.

II. MOTIVATION AND GOALS

The initial idea for this project was proposed by a group member that had personally been run off the road by a truck that was unable to see him. Moreover, each team member personally knows someone that was in an accident caused by a truck. This, in addition to the research mentioned in the previous section, prompted the team to try and make the roads safer using Truck Smart. The exact goals of the system were as follows:

First, the system should be as accurate as possible. Accuracy is extremely critical for this project considering there will be lives on the line, should it fail to display the correct information. Second, the system must be safe and efficient. We do not want the system to distract drivers from looking at the road but the information should also be clearly visible to the driver. Third, the system must be very easy to use. Truck drivers have very busy lives and they drive nonstop across the country daily. We want truck drivers to be able to use this system regardless of their technological background and with minimal effort. Fourth, the system needs to be portable, allowing drivers to easily move it from one trailer to another when they drop off and pick up trailers. Fifth, the system should have a low level of power consumption. The user should not have to worry about the system running out of power while driving. Finally, the system should have a low cost. All truck drivers or corporations should be able to afford it while keeping them, as well as the surrounding drivers, safe.

III. SYSTEM DESIGN

The overall system is based on the location of the sensors. For proof of concept, three sensors will be place strategically in three key locations across the truck and its trailer. The location of the sensors can be seen in the figure below.

The overall system is composed of four total components. Three sensors collecting data from the blind spots to determine whether there is a vehicle in the blind

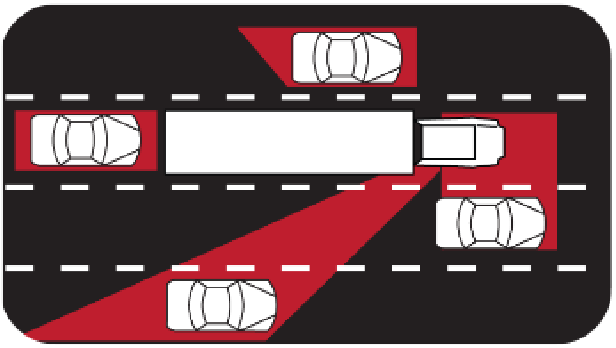


Figure 1 - Blind Spot Locations

spot or not. Inside the truck's cabin, there will be a hub system with a set of LEDs. Depending on where the wireless data transmission is coming from, the LEDs will blink to alert the driver if a vehicle enters the blind spot. Once a vehicle leaves the blind spot, the corresponding LED will automatically turn off. In addition, a fault LED will be used to alert the driver if any of the sensors are turned off or outside the network. The fault LED is a simple red LED located adjacent to its corresponding status LED. The overall design and implementation of the system can be seen in the figure below.

The left side of the figure corresponds to the sensor units. All three sensors have the same exact components. A battery is used to power the sensors, microcontroller, and XBee transceivers. The initial voltage of the battery is scaled down to 5 Volts to be able to supply the necessary power to the sensor and MCU. Another regulator is used to scale down the voltage to 3.3 and provide the wireless transceiver the necessary power it needs to operate. If a vehicle appears in the blind spot, the sensor will detect it. The sensor's output will be processed by the microcontroller unit and if the location of the vehicle within the blind spot is above the trigger distance, the corresponding sensor's number will be sent across the network to the hub unit.

The right side of the diagram represents the hub unit. The hub is powered directly from the DC port located in the truck's cabin. The hub is composed of the same set of components as the ones in the sensors except for the physical sensor. In addition, the hub contains the LED bank used to output the blind spot output as well as the fault detection status.

A. Microcontroller

The Truck Smart system uses one microcontroller for the hub and one for each of its sensors. The MCU in each sensor will allow for data transmission between the sensor and the XBee unit connected to it. The

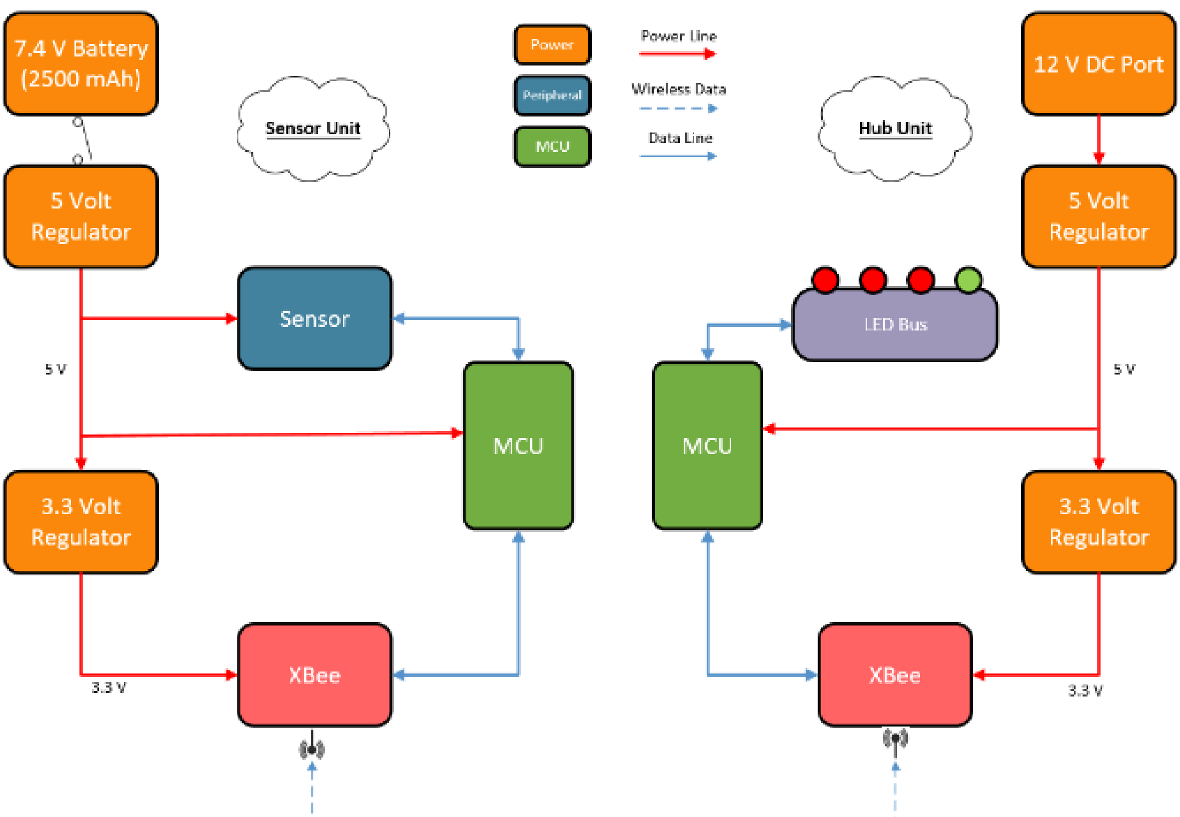


Figure 2 - Overall Block Diagram

data will then be sent to the base unit where its MCU will process the data and output the results accordingly.

For the sake of simplicity, the same MCU was used in each of the sensors and the hub. From an engineering standpoint, this made both creating and maintaining the system a lot easier. Only one type of MCU will need to be understood and any worry of incompatibilities will be avoided. From a marketing standpoint, having only a single type of MCU will make purchasing hardware parts in bulk number easier. This will lower the cost to build the system which, in turn, will result in a more economically priced product. To work well for both the hub unit and the sensor unit, the chosen MCU should have a low-power functionality for simple tasks such as transferring data from the sensor to the hub and the performance necessary to process the information gathered by the sensors and output it to the user in various ways.

While there were a wide variety of microcontrollers to choose from, the two that stood out the most were the MSP430 and ATmega328P. The MSP 430 was chosen as a potential microcontroller due to the team's familiarity with it from past classes. The ATmega328P was looked at because of its popularity as the chip that is used in the Arduino Uno, a prominent development board.

When it came to deciding between the two chips, five main factors were used. The first was power consumption. This was especially important the drivers should not have to worry about the sensors running out of power before they reach their destination. The second factor was cost. A system that promotes safety should be adopted by as many people as possible. One of the easiest ways to do that is to make the final product affordable. The third factor was memory size, both flash and RAM. It should have enough memory to properly store and run the code without any issues. The fourth factor was processing speed. The MCU should be able to process the required amount of data with as little delay as possible. This was especially important for the hub unit which processes the all data received from every sensor and then must display it to the user. The final category was pin count. In addition to being able to support the ZigBee, ultrasonic sensor, and LEDs, the system should have leftover pins for future upgrades such as cameras. In the end the ATmega328P came out as the clear winner of every category except for cost, in which it was 33% more expensive. The team decided the capabilities of the ATmega328P were worth the cost and it was chosen as the microcontroller for the Truck Smart system.

A bonus of using the ATmega328P was that code could be easily tested using the Arduino Uno development board before being used on a breadboard of PCB. This helped ease the development process.

B. Wireless Communication

The main goal when designing the Truck Smart system is that it must be adaptable and easy to plug and play into different truck trailers regardless of the size of the trailer. For practicality and ease of installation, wireless communication was chosen as the means of data transfer in between the sensors and hub. There were several wireless technologies that were taken into consideration such as Wi-Fi, Bluetooth and ZigBee. While Wi-Fi proved to be too powerful for our needs, and Bluetooth too power hungry, ZigBee is the best technology for the system's needs. However, when using ZigBee technology, developers are restricted to small data rates which will prevent us from adding features such as live video streaming or any other functionality that will require large wireless data transfers.

The ZigBee component available to be used for the Truck Smart system is the XBee module. This low-power module can be integrated into microcontrollers seamlessly and combines RF technology with the ZigBee standardized protocol. Having a pre-existing protocol available means the Truck Smart system design does not have to account for proprietary RF communication development. The Digimesh capability of the ZigBee devices means there is no need for a router to be included in the system design. The XBee module available has an RF power output of 1 mW. The component itself consumes approximately 165 mW. The output power gives the XBee module a transmit/receive range of over 100 feet, which exceeds the requirement of 63 feet for the Truck Smart system. There is a wide range of available ZigBee technologies available for integration, all of which are small and do not require many special provisions.

C. Blind Spot Sensor

The Truck Smart system uses distance sensors as a means of blind spot detection. Selecting the right sensor for this system was very crucial because the reliability and accuracy of the sensor directly affects the performance of the system. A false detection or failure to detect a vehicle can result in an accident. Therefore, the team carefully considered the pros and cons of three kinds of sensor before selecting the one that's right for this product. The options were: Infrared, Ultrasonic, and Radar. Even though infrared sensors are cheaper, faster, and smaller than ultrasonic sensors, they only provide high accuracy for indoor applications. Therefore the team decided to go with an ultrasonic sensor because that would be more adaptable for this system.

Ultrasonic sensors are based on measuring the properties of sound waves with frequency above the human audible range. They are based on three physical principles: time of flight, the Doppler Effect, and the attenuation of sound waves. Ultrasonic sensors are nonintrusive in that they do not require physical contact with their target. They can measure distances with a precision of 3 cm. Distance is calculated using the equation; where time = the time between when an ultrasonic wave is transmitted and when it is received (it is divided by 2 because the sound wave has to travel to the object and back so the actual distance is only half of this number). The main advantage of ultrasonic sensors is that measurements may be made without touching or otherwise impeding the target. In addition, depending on the distance measured, measurement is very quick; it takes roughly 6ms for sound to travel 1m.

The ultrasonic sensor used in this system is LV MaxSonar MB1000. This is a low cost, high accuracy rangefinder. The sensor takes a 2.5V-5.5V supply and has a very low current draw of 2 mA making it very suitable for long battery life. The sensor also features fast measurement cycles of 20 mS. This model has a maximum range of 21 foot which is well suitable for a typical highway length of 12 feet.

The Truck Smart system requires both mobile and fixed power supplies. The system's peripheral sensors require batteries that are energy-dense, lightweight, and can easily be recharged. The system's hub uses a fixed power supply provided by the 12V DC port in the vehicle cabin. An 18 hour battery life requirement was established to ensure the system would be capable of operating throughout the course of an entire day's drive without having to recharge. To meet this requirement, a set of 2200 mAh lithium polymer batteries were used, based on the power consumption calculations shown below (table 1). The estimated lifetime of a sensor battery is approximately 23.2 hours. These calculations include an estimated voltage regulator efficiency of 75%. The chosen batteries can also be charged all at once using a 3-port charger.

V. SYSTEM HOUSING

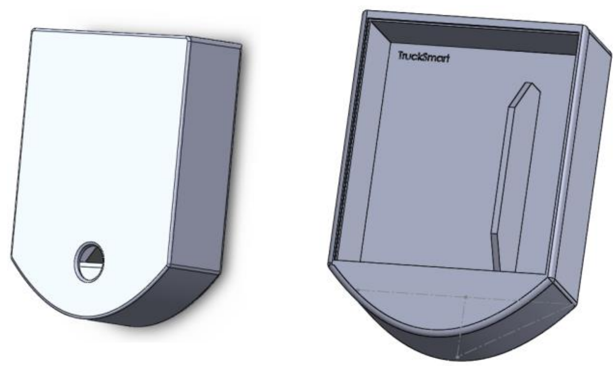


Figure 3 - Housing

In order to house and protect the Truck Smart system, the housing was designed to withstand the expected conditions the system will be facing. Some environmental factors include 70+ mph wind, rain, heat, freezing conditions, and condensation. To tackle the conditions concerning water, the encasement has tight tolerances silicon sealant around all system-critical areas. The primary areas of focus for preventing housing leakage are near the sensor port and on the bottom flat surface cover plate.

On the back of the housing, neodymium magnets are used as an attachment mechanism. After calculations and testing, these magnets have been proven effective at holding the weight of the system under normal driving conditions. Force calculations based on the magnet's pull force have confirmed that there is enough magnetic strength to overcome the force of drag at 70 mph.

TruckSmart Peripheral Sensor Component Power Consumption					
Active Components	Operating Voltage (V)	Operating (Idle) Current (mA)	Active Current (mA)	Average Current Draw (mA) @ 0% Idle	Power Consumption (mW)
EZ-MB1000 Sonar Sensor	5	2	2	2	10
Xbee RF Module	3.3	29	29	29	95.7
ATmega328P Chip @ 16Mhz	5	16.43	21.8	19.12	95.58
Total Load Draw	N/A	NA	NA	50.12	201.28
Regulator Efficiency (est.)*	75%	* Hub power consumption is estimated to peak at 860 mW and idle at 260mW. ** Due to battery constraints, sensor consumption is deemed higher priority.			
Battery Longevity (mAh)	2200				
Lifetime est. (hours)	32.92				

Table 1 - Power Consumption

The material used to prototype this housing was 3D-printed ABS. This material is extremely durable and is capable of withstanding impacts from rocks and small debris without concern for cracking. The inside portion has been designed to separate the battery from the PCB, channel wiring for power and data lines, and also angle the sensor appropriately to sense vehicles slightly behind where the sensor is placed on the truck.

IV. ELECTRICAL DESIGN

The Truck Smart electrical design is compact, modular, and efficient. Linear voltage regulators were used to step the voltage down from 12V (cabin power supply) and 7.4V (batteries) to 5V and 3.3V. Along with these voltage regulators are multiple bypass capacitors that have been included to prevent voltage spikes. 5V is delivered to the ATMega328P and 3.3V is delivered to the XBee transceiver. The ATMega328P then provides the necessary voltages for functions like notification (LEDs),

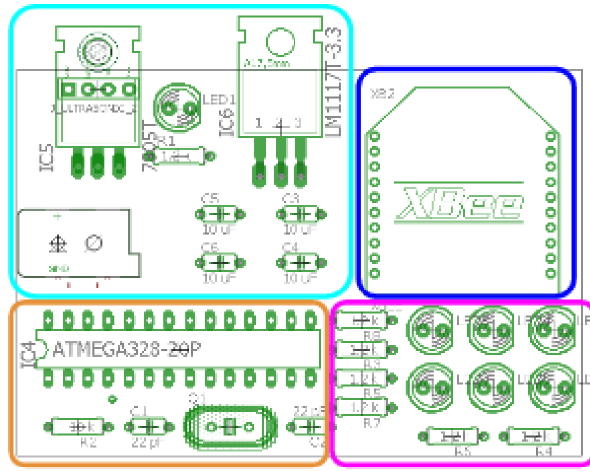


Figure 5 - PCB Layout

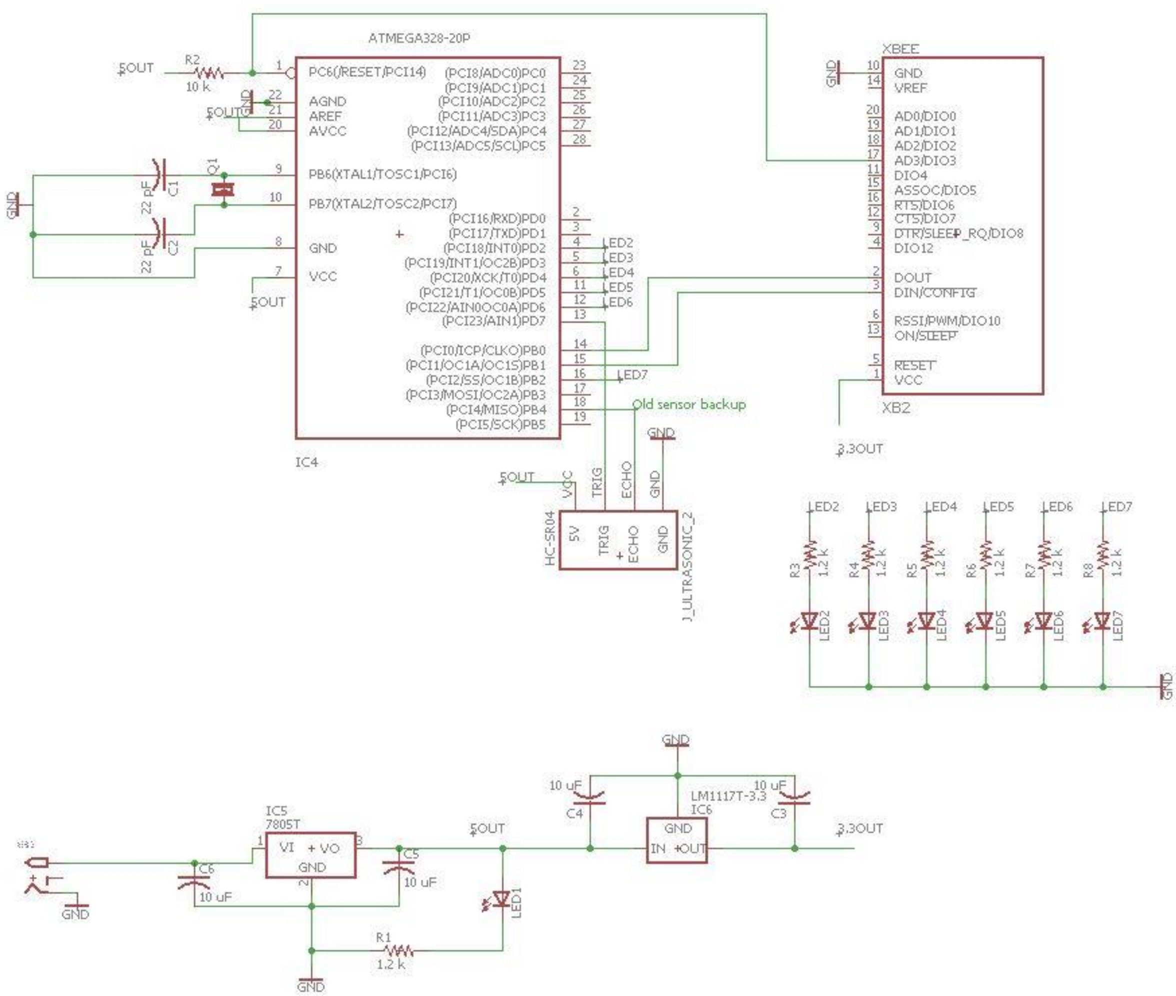


Figure 4 - PCB Schematic

packet transmit/receive via the Tx and Rx lines, and also internal data handling and processing for logic operations. Power LEDs have also been added for the sake of practicality. The resistances corresponding to the notification LEDs have also been biased to allow for optimal voltage levels based on the color of the LEDs (ranging anywhere between 1.5V - 3.8V).

The ATMega328P also required a 16 MHz quartz clock paired with parallel decoupling capacitors to filter out any noise. The schematic, shown in Figure 5, demonstrates the circuit's modularity and provisions for future functions. The four primary functions of the circuit include communications, notifications, power distribution, and MCU operations. These functions were transposed from the schematic to the PCB board design. Figure 6 shows the untraced layout of the PCB and how these four functions have been organized and condensed. The PCB has been designed to be interchangeable for both the system hub and the peripheral sensors. This method of design has proved practical in prototyping and has cut costs dramatically.

VI. Software Design

The ZigBee units were setup using XTCU. The microcontrollers were programmed using the Arduino language, based on C and C++, using the Arduino IDE. The software was specialized for each type of unit, the sensor and the hub.

A. ZigBee

The data transmission uses a unicast approach with end-to-end acknowledgement. In other words, once a transmission is sent to the base, it will wait for an acknowledgment from the hub unit before marking the package as "sent". All devices in a ZigBee network can only send data to nodes within the same network. A ZigBee network, regardless of the number of devices that it contains, is called a "Personal Area Network" (PAN). Each PAN contains a unique identifier, which helps prevent interference as well as confusion with other ZigBee networks when sending data. A ZigBee PAN is composed of coordinators (ZCs), ZigBee Routers (ZRs), and ZigBee end devices (ZEDs). Only coordinators can form a network while ZigBee routers and end devices can join a network; but not create one. A ZigBee Extended PAN ID (EPID) is a 64-bit value set for the entire network by the network coordinator.

In the system, there is the possibility of two trucks using the same system while being within close proximity from each other. This can cause interference and data from a sensor from one system ending up being sent to the other system that is operating right next to it. To prevent this from happening, the ZigBee protocol checks where the data is coming from. Secondly, it compares the PAN ID for each of the devices that are sending the data. Finally, if the ID is defined in the network, it receives and processes the data; otherwise, the data is disregarded. The PAN IDs used are unique for every channel.

Sending a message and receiving a message in between two devices will follow a set of steps. First, the sender (AT Mega microcontroller) sends a ZigBee transmit request API frame to the XBee module which will contain the destination address and the message. For the second step, the receiving device will receive a ZigBee Receive Packet API frame which will contain the sender's address and the message. It will also send back to the sender an acknowledgement that the data was successfully received. Lastly, the sender acknowledges within itself that the receiver could obtain (or not) the previously sent data. This acknowledge is knows as a "ZigBee Transmit Status".

The process is illustrated in the following diagram. Each of the vertical lines indicates a component in the system while the arrows represent the messages moving in between them. The transmission starts at the top in the MCU, the request is sent to the XBee module, and the packet is transmitted. The XBee on the receiving side gets the packet, which goes into the receiving MCU. Finally, the receiving device sends an acknowledgment (Ack) back to the sending device's XBee module which ends up transmitting the status response to the sending microcontroller.

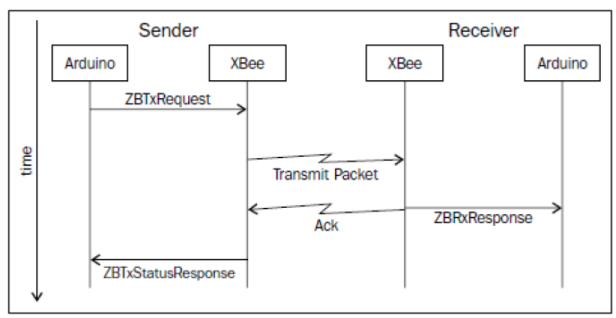


Figure 6 - XBee Transmission Flow

From the diagram in the figure above, the initial data being sent in between the sending microcontroller and the XBee module is the "ZBTxRequest". This type of request is known as a ZigBee Transmit Request and it contains several important fields. The first being the 64 – bit destination address which will contain where to send the data packet. The second field is optional and consists of the 16 – bit destination address and is used if the sending device knows the address of the receiving node to save the overhead of looking up an address on the network. The last field is known as "the payload" and consists the actual content of the message being sent. For the Truck Smart system this will be composed of the sensor's output and location.

The actual data that is being sent such as the sensor's output is fully encrypted and protected across the network. Another layer of security the system has in place is the use of a network key. The network key is equivalent to entering a password when logging into your local Wi-Fi network. All members of the network must know this key to be able to send and receive data across the network. The final layer of security is that the system disables network joining after all members of the network have joined. This will prevent any new devices from joining after the network is up and running with all its members being active.

A. Hub Unit

The hub unit will be displayed in the cabin of the vehicle in a spot easily accessible by the driver. It acts as the liaison between the sensors and the user. The hub unit has five main functions that it was programmed to do. First, it must create the ZigBee Personal Area Network. Second, it will then manage this network by detecting any sensor units with the same network ID, adding them to the network, and continuously keeping track of each sensor unit's status. Third, it will take in all data sent each sensor to the hub and process it. Fourth, it will then parse this data and display the corresponding information to the user using various LEDs. Finally, it will warn the user of any system malfunctions. This includes things such as a sensor unit that has not updated its status in over 30 seconds. This check is done by logging the time that each sensor sends data. Every 30 seconds, the hub unit will check that all sensors in the system have updated their status by checking the logs.

A. Sensor Unit

Like the hub unit, the sensor unit also has five main tasks. When the unit is first powered up, it will scan for and attempt to join a ZigBee PAN that matches its network ID. Once it joins a network, it will then send a test transmission to make sure both the wireless communication and the sensor is working properly. Once everything is confirmed to be working, it will enter its main stage which is run in a continuous loop. It will first read data from the sensor and compare it to the previous state, which will be 0 or 1 based on whether the sensor detected anything in its proximity. If the state differs, the sensor will the send the updated data to the hub unit, log the time, and repeat the loop again. If the state is the same as the previous state, it will then perform a check to see if the sensor has sent any data to the hub in the last 30 seconds. If not, it will send the data regardless of previous state. If it has already sent data in the previous 30 seconds, it will finish this iteration of the loop without performing anything. The software flow of the sensor unit can be seen in Figure 7.

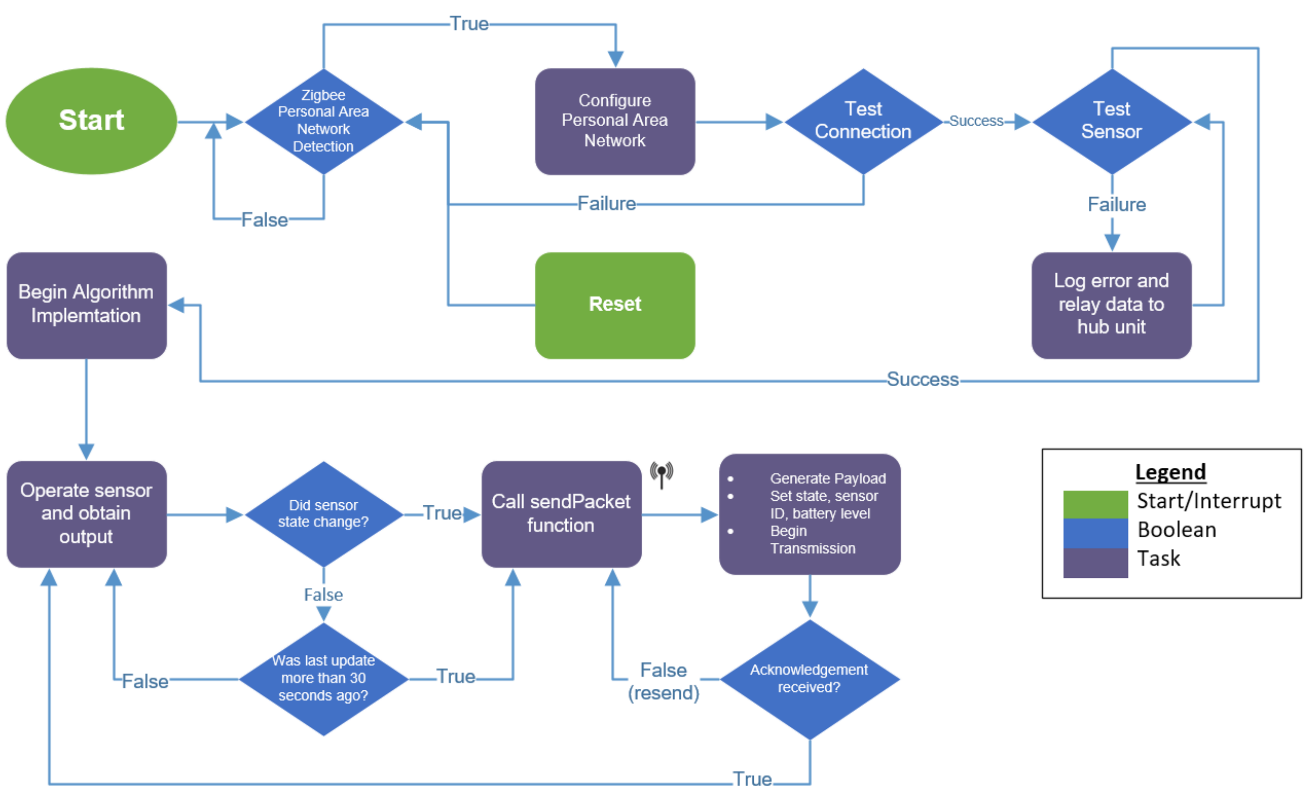


Figure 7 - Sensor Software Flow

VII. CONCLUSION

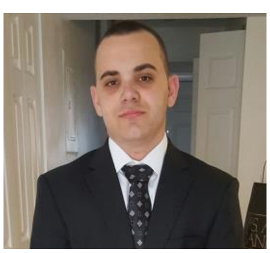
Truck Smart's core infrastructure consists of many simple components that, when integrated properly, deliver a marketable function to an industry in need of an update in safety technology. Considerations have been taken in the design phase to make the end user's safety the number one priority for the Truck Smart system. Second hand factors, such as system testing, fault reporting, and even the cognitive impact on the user, have all been accounted for to ensure the end product is unrivaled to any similar technology of its kind. The design workload has been evenly distributed among the computer engineering and electrical engineering disciplines. The Truck Smart system has been technically well-rounded to cover all bases.

VIII. ACKNOWLEDGEMENTS

The Truck Smart team would like to thank Dr. Lei Wei for his time and assistance throughout the semesters. They would also like acknowledge the TI Innovation Lab at UCF for providing a workspace, tools, and a 3D print. The team would also like to thank Reynold Marrero for allowing us to test our system in his truck.

IX. BIOGRAPHIES

Abhijith Santhoshkumar is currently a senior at the University of Central Florida. He is majoring in Computer Engineering and will graduate in May 2017. He is pursuing a career in software engineering. He will be joining Lockheed Martin as a full-time software engineer upon graduation.



Aris Socorro is currently a senior at UCF and will be graduating in May of 2017 with a bachelor's degree in Computer Engineering. He worked as a system engineer intern in the military training and simulation field with Alion Science and Technology. He currently interns at Lockheed Martin as a software engineer in the development of logistics system for military aircraft. He will be joining Lockheed Martin as a full-time software engineer upon graduation. He plans to pursue a Master's degree in computer science.

David Sheets is currently a senior at the University of Central Florida and will receive a Bachelor's of Science in Electrical Engineering in May of 2017. He has held internships at Lockheed Martin and Northrop Grumman. He has recently accepted an offer under the Strategic Systems Specialty Engineering Division of Northrop Grumman, focusing primarily on software development. He plans to pursue a Masters in Computer Science or Quantitative Financial Economics.

Neel Sheth is currently a senior at the University of Central Florida and will receive a Bachelor's of Science in Electrical Engineering with a minor in intelligent robotic systems in May of 2017. He is currently doing a co-op at Nelson Engineering. He has recently accepted a full time offer under Vehicle Engineering Division of Northrop Grumman as an Electrical System Design Integration Engineer.

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