The University of Southern Mississippi
The Aquila Digital Community

Honors Theses | Honors College

Fall 12-2018

Autonomous Collision Avoidance in Small Scale Vehicles

Justin T. Sharpe
University of Southern Mississippi

Follow this and additional works at: https://aquila.usm.edu/honors_theses

Part of the Robotics Commons

Recommended Citation

Sharpe, Justin T., "Autonomous Collision Avoidance in Small Scale Vehicles" (2018). *Honors Theses*. 623.
https://aquila.usm.edu/honors_theses/623

This Honors College Thesis is brought to you for free and open access by the Honors College at The Aquila Digital Community. It has been accepted for inclusion in Honors Theses by an authorized administrator of The Aquila Digital Community. For more information, please contact Joshua.Cromwell@usm.edu, Jennie.Vance@usm.edu.

The University of Southern Mississippi

Autonomous Collision Avoidance in Small Scale Vehicles

by

Justin Sharpe

A Thesis
Submitted to the Honors College of
The University of Southern Mississippi
in Partial Fulfillment
of Honors Requirements

December 2018

Approved by:

Stephen Todd Adams, Thesis Adviser
Computer Engineering Technology

Andrew Sung, Ph.D., Director
School of Computing Sciences and
Computer Engineering

Ellen Weinauer, Ph.D., Dean
Honors College

Abstract

The undergraduate research performed in this study focused on autonomous collision avoidance in small scale vehicles. The goal of this study was to find equipment to build a fully autonomous small scale vehicle for use in different applications. Radio frequency communication, ultrasonic sensors, and single board computers were used to create an autonomous vehicle for multiple applications. Different communication protocols and sensors were investigated, and an explanation was specified concerning the hardware choice. The main communication protocol tested was Long Range Wide Area Network, and the main electronics tested and used were ultrasonic sensors, First Person View cameras, and the Arduino Mega 2560. Though the main communication protocol performed worse than anticipated, a different communication protocol was chosen and tested. The secondary communication protocol produced more promising results.

Keywords: Long Range, Low Power, Radio Frequency

Acknowledgements

I would like to thank MD5 Proof of Concept Center at the University of Southern Mississippi for providing the funding for the equipment necessary for this project.

I would like to thank Keith Conley, Stephen Adams, and Amer Dawoud, Ph.D for the knowledge and expertise in the project field.

I would like to thank my wife, Melody Sharpe, for the emotional support and review that she provided.

I would like to thank my parents, Christopher and Jennifer Sharpe, for all of the financial and emotional support that they provided.

Table of Contents

List of Figures

List of Abbreviations

ATV	All-Terrain Vehicle
COTS	Commercial-Off-the-Shelf
DC	Direct Current
EMF	Electromotive Force
FOB	Forward Operating Base
FPV	First Person View
IED	Improvised Explosives Device
LIDAR	Laser Identification Detection and Ranging
LoRa	Long Range
LoRaWAN	Long Range Wide Area Network
LPWAN	Low Power Wide Area Network
NUST	National University of Science and Technology
P2P	Point-to-Point
RC	Radio Control
RF	Radio Frequency
UAS	Unmanned Aerial Systems

Chapter 1: Introduction

The radio control (RC) hobby can be very expensive, costing thousands of dollars per machine. Human error is common and repairs can be quite expensive. If long range (LoRa) or long-distance wireless communication technology, sonar collision avoidance, and a first-person view (FPV) camera were incorporated into these machines human error could be eliminated, reducing collisions significantly, and the corresponding cost of the repairs. This project includes implementation of Long Range Wide Area Network (LoRaWAN) technology, sonar collision avoidance technology, and a FPV camera into a radio controlled trophy truck. LoRaWAN is a wireless technology able to be incorporated into low power applications requiring transmission ranges of up to 15 kilometers. It provides secure bi-directional communication between the control source and the RC vehicle. LoRaWAN, in conjunction with a sonar camera and a FPV camera, will allow the user to control the vehicle over a significant range and view the terrain local to the vehicle within a distance of 15 kilometers. The sonar camera allows the vehicle to avoid imminent obstacles within its path. Collision avoidance will allow the RC vehicle to perform autonomously, allowing the vehicle to choose the most optimal path around obstacles. The programming is complicated due to the difficulty of interfacing and interpreting each of the hardware module's input/output signals. As the main processor for the project, the computer utilizes multiple inputs to monitor data from the hardware modules to autonomously control a steering servo to control the necessary steering angle. The FPV camera will allow the user to see what the vehicle sees and where it is heading, allowing the user to take over at any time if they wish, when accompanied by the controller.

The RC hobby is extensive, with ever increasing levels of expense beyond introductory RC cars. Due to the uncommon appearance of autonomous applications, the equipment is quite expensive. The equipment for small scale applications, however; is not as expensive as the industrial equipment currently used in similar, larger scale applications. A commercial off-the-shelf (COTS) LoRaWAN module can cost up to $500, with the sonar camera and the FPV camera costing $50 each. The machine will also need an external battery costing $65. The sum of the necessary parts is approximately $1000. If this technology were implemented more frequently, the price would be significantly reduced, making the machine more affordable and stimulating the market. The RC vehicle used in this project costs $500 for the chassis. Electronics cost an additional $200. The more times autonomous hardware is implemented, the more affordable it becomes,especially for beginners, who could become involved with this hobby without a significant investment. By integrating the proposed hardware modules and the RC vehicle, the project demonstrates a cheaper solution to more expensive, multi-thousand-dollar industrial or military drones. Integrating relatively inexpensive hobby level RC vehicles with the aforementioned hardware modules provides a cost effective platform for military land based drones. From IED eradication to supply distribution to combat elements beyond Forward Operating Bases (FOBs), drones based on the integration of low cost RC vehicle platforms and COTS hardware modules could provide essential services to combat troops. As a secondary purpose, the modified RC vehicle could be designed and utilized as an autonomous land survey vehicle to access areas that a human or quad-copter drone would have difficulty navigating.

Chapter 2: Literature Review

Remote Control Vehicle

The platform for this project is a Yeti Score Trophy Truck Kit manufactured by Axial Racing®. This kit was chosen due to its relatively large size in comparison to other one tenth scale vehicles. The vehicle itself is 23 inches long, 12 inches high, and has a ground clearance of 1.7 inches. Additionally, the vehicle has an off-road focused suspension and shaft-driven four-wheel drive providing better traction and the ability to traverse difficult terrain with ease.

The patent for the remote-control vehicle ushered in a new age of model vehicles. Being remotely controlled allowed for vehicles to become much smaller in size, permitting use in many different applications where a regular vehicle, even something as small as an all-terrain vehicle (ATV) would be ineffective. It also allowed for small batteries to power direct current (DC) motors to propel the vehicle forward or backwards without using a transmission. Reversing the polarity of the electromotive force (EMF) spins the motor, and thus all gearing attached to it, in the reverse direction[1].

LPWAN

The primary piece of hardware employed in this project is a LoRaWAN evaluation module. This hardware module affords control from a remote location, allowing the vehicle to be controlled in areas containing improvised explosives devices (IEDs) from a remote location. An article in the journal "Understanding the Limits of LoRaWAN" gives insight into the overall range of the module as well as the battery life and explanation of ease of use of the module. Low-Power Wide Area Network (LPWAN) is a form of long range communication, much like a cellular connection. The range on the LPWAN is 2 to 5 km in urban areas and up to 15 km in suburban areas. That, coupled with the security of LPWAN, makes it a very good alternative to cellular networks. The battery life of the module is around ten years[2]. According to “Low Power Wireless Scenarios and Techniques for Saving Bandwidth Without Sacrificing Security," smaller messages have a higher chance of being transmitted without interference than larger messages[3]. This is because the smaller packages have a much lower chance of interfering with other packages on the long range network and therefore have a much smaller footprint, which gives them a much lower chance of being intercepted and the information in them stolen[3].

According to an article in the journal "Survey of Radio Resource Management Issues and Proposals for Energy-Efficient Cellular Networks That will Cover Billions of Machines", LoRaWAN or LPWAN is a new machine-to-machine communication scheme, having the possibility to replace cellular connections, such as 2, 3, and 4G connections[4]. On a chart of popularity of implementation, the LPWAN connection is rising exponentially in popularity, the 2G connection is leveling out, and 3G and 4G are slightly rising in popularity[4]. The journal article "Evaluation of LoRa LPWAN Technology for Indoor Remote Health and Wellbeing Monitoring" demonstrated that over an entire campus, only one base station was used, and that the success rate of transmission of information was 96.7%, not including retransmissions. This means that the LPWAN network is much more reliable than an ordinary cellular network[5]. Due to the fact that the network is more reliable and more secure, the network can replace a normal cellular network. With many updates or changes to LPWAN, speed can be obtained by sacrificing another characteristic, such as user friendliness. In this case, that is not true, as it is more secure, more reliable, and easier to manage.

Sonar Collision Avoidance

The second piece of hardware implemented into this project is a sonar collision avoidance camera. While sonar is not as accurate as a 3D camera, it is less expensive. For the sonar camera, as little as $4 is required for a camera that has an effective, accurate range of as close as 2 cm and as far as 5 m. An article in the journal "Sonar based Outdoor Vehicle Navigation and Collision Avoidance" gives some insight about the types of applications of sonar. Sonar is quite effective indoors for robotics applications, and can even act as a line follower. In the experiment performed, the autonomous vehicle Naviab followed a set of railroad tracks using a sonar camera as a line follower. The sonar camera receives images from the ultrasonic pulses and registers the railroad tracks as a wall. This allows the robot to have a range set as a guidance parameter to keep the vehicle as close as possible to the tracks[6]. This method of collision avoidance is what is being implemented in this project. The project in this instance is using walls as guidance. The autonomous land drone will have to navigate in between walls using the HC-SR04 ultrasonic sensor. The patent "Ultrasonic Obstacle Detector" explains some uses of the sonar camera. The main implementation is extremely similar to the implementation in this project. The purpose of the implementation in the journal is vehicle obstacle recognition. This uses Laser Identification Detection and Ranging (LIDAR) technology to take a "picture" of the surrounding area and warn the driver of the automobile if there is an obstacle and how close the obstacle is[7]. As compared to the $4 sonar camera, which has an effective range of up to 5 m, the laser range finder has an effective range of up to 1.3 km. While this is significantly better, the laser finder costs $400. According to the patent, the laser range finder uses laser pulse timing. Although the range finder has a

4500 foot range, 4500 feet is a much larger range than necessary for these vehicles. For this one tenth scale land drone, sixteen feet is ample distance to let the vehicle know there is an obstacle. This implementation of sonar, rather than the much higher range laser finder, saves the individual $396, which is a significant amount[8].

First Person View

If this project were funded by outside sources, it would include an FPV, or first-person view, drone camera. This camera would allow the user to interface with the vehicle directly to be able to see the direction in which it is heading and see the obstacles ahead of it in addition to using the ultrasonic sensors to detect walls to the left and right of the vehicle. This would be especially useful in tight areas in which a human could not travel. Considering the fact that this vehicle will have a micro-controller, adding a FPV camera and allowing the camera to interface with the controller would allow the user to see transmitted images for surveying purposes[9]. The use of camera drones has even been implemented into the military, as they use drones not only for survey purposes, but also for air-strike assistance on the battlefield. This not only gives soldiers a better idea of their surroundings, but also can help eliminate Improvised Explosives Devices (IEDs). The elimination of these IEDs and reduction in manned drone air-strikes reduces both soldier and civilian casualties[10].

P2P RF Interface

The second communication protocol tested in this study was a Point-to-Point (P2P) RF interface, the DragonLink Advanced Complete System. This RF interface was tested as a comparison to the LoRa protocol to determine its reliability, connectivity distance, and ease of use. The DragonLink system has been used in surveillance and disaster relief applications. The National University of Science and Technology (NUST) in Islamabad, Pakistan performed a study on different radio systems to be used in disaster relief unmanned aerial systems (UAS) applications. Among the five different radio systems tested was the DragonLink, which was found to have tied for the longest range, and was praised for its connectivity, reliability, and adaptability[11]. The DragonLink was designed for use with the aforementioned FPV camera, and would be a suitable choice for this project using the FPV camera.

Chapter 3: Methodology

The methodology of this research relies primarily on the electronics installed on the vehicle kit. The installed equipment consists of 4 HC-SR04 Ultrasonic Sensors, a LoRaWAN module, and a FPV camera. The ultrasonic sensors were chosen over Laser LIDAR due to the price, as well as ease of integration into the project. The ultrasonic sensors have four electrical connection pins: a power pin, a ground pin, a trigger pin, and an echo pin. These pins allow the user to provide power to the sensor, and through software activate the trigger pin, labeled TrigPin, and read the echo pin to send out an ultrasonic pulse and detect the range of an obstacle in front of the sensor. The signals from the sensors are received and processed by an Arduino Mega 2650, the microcontroller chosen for the project, which sends the data to the LoRaWAN module, which then sends the information back to the networked computer. The project relies on principles of data acquisition and digital feedback, and utilizes sensors installed on the vehicle to provide relevant information to the Arduino Mega 2650, which controls the response of the vehicle. Data from sensors on the vehicle elicit a response from the Arduino Mega 2560, which adjusts the DC wheel motors to control the relative speed of the vehicle, and the steering DC servo-motor to control the directional wheels as necessary for collision avoidance. The code consists of multiple “For” and “If-Then” loops. In C programming language, these loops allow the Arduino’s digital inputs to be analyzed and tested under different conditions. As an example, if the vehicle needs to perform an emergency stop, the code is written to act on any data indicating that the sensor had detected an object. The Arduino would then send a control signal to the motor controller to stop the motors completely. This can be written similarly as follows:

```
if(trigPin = HIGH)
{
    vehicleSpeed = 0;
}
```

If the vehicle is required to slow down, the code may read more like the following:

```
if(trigPin = HIGH)
{
   if(distance <= 10 (cm))
   {
         vehicleSpeed = 0;
   }
   else
   {
         vehicleSpeed = (whatever
function I write to slow down);
   }
}
```

This sample of code uses multiple loops that allow the code to realize there is an obstacle, and decide whether to slow down or stop the vehicle, or force it to alter its direction to avoid a collision. With the LoRaWAN module on the vehicle, data can be transmitted through the module wirelessly to a networked computer of the operator's choosing, as long as it is within the constraints of the module. With the module connected to the computer, the user can observe the operation of the vehicle and finalize the software control calibration. Changing the refresh rate in the software will allow more data to be collected; however, caution is essential, as the memory on the Arduino is limited. This will also allow the user to observe the frame-rate transmission of the module, therefore helping them decide at what speed the vehicle can be driven effectively. The effective speed of the vehicle can be altered with higher quality parts. However, this project is aimed at speeds less than twenty miles per hour; for this reason the hardware choices were reasonable, with a total electronic cost of approximately $30.

The vehicle kit is the Axial Yeti SCORE 1/10th Scale Trophy Truck. This vehicle kit was chosen due to its off-road focused suspension and four-wheel-drive. The attributes of this vehicle allow the project to be modified into a land survey vehicle, affording mobility in places where a human being could not traverse without the destruction or alteration of land, thereby saving time and money by not requiring or having to wait for services such as deforestation or leveling of land.

Chapter 4: Results/Discussion

The following images are images from the testing done with the LoRa communication and the P2P RF interface manufactured by DragonLink.

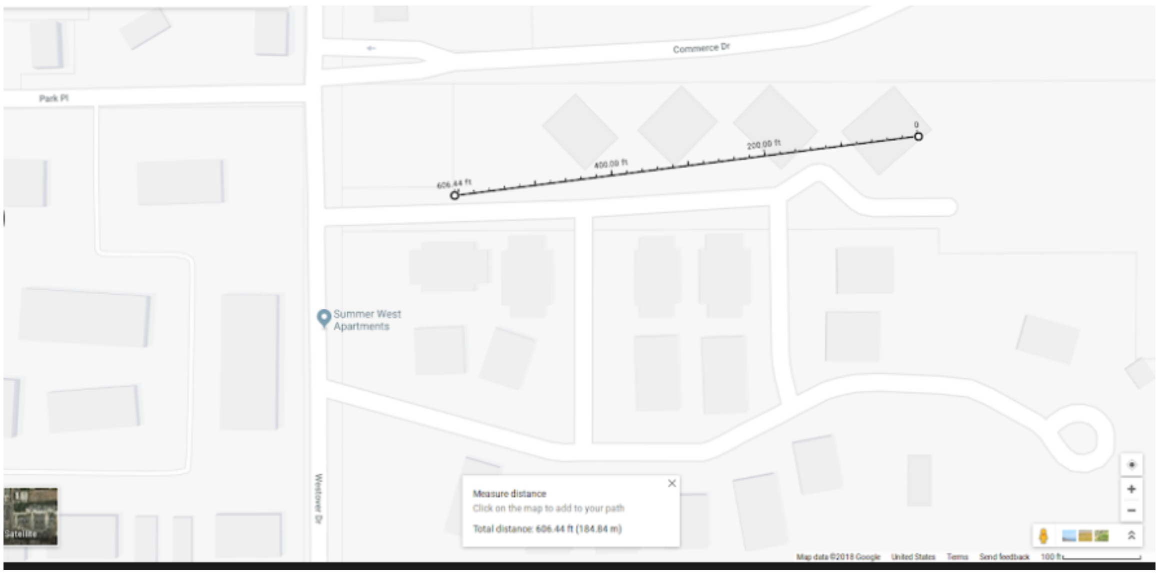

Figure 1A. **Apartment Complex LoRa Connectivity Test.** The maximum distance achievable at the apartment complex was 606 feet. After this distance, the devices would disconnect from one another and drop packets of data.

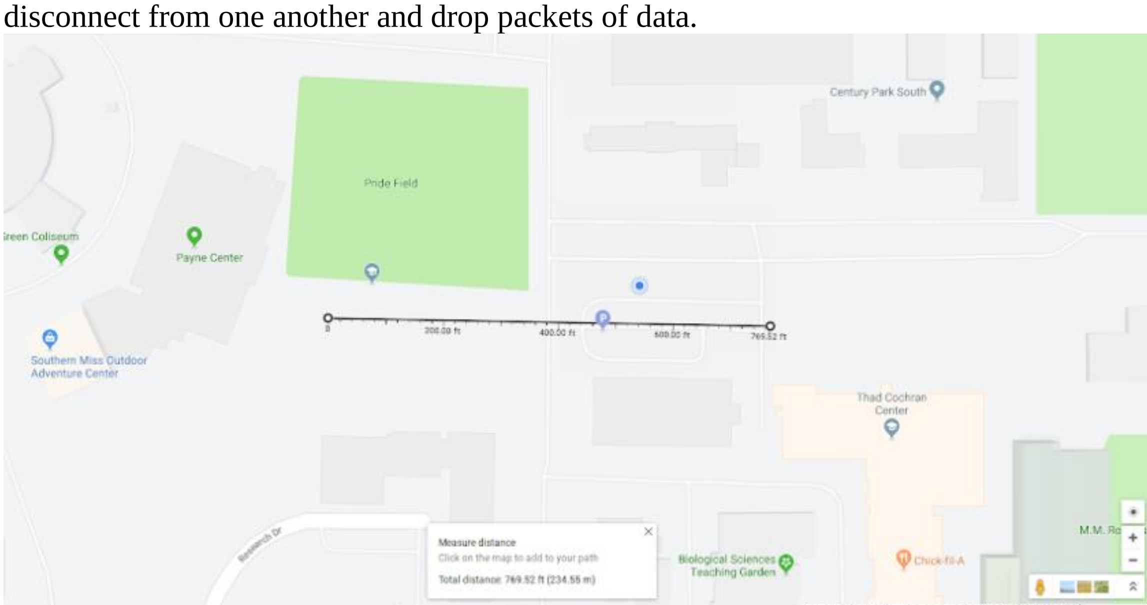

Figure 1B. **Campus LoRa Connectivity Test.** The maximum achievable distance was 769 feet. After this distance, the devices would disconnect from one another and drop packets of data.

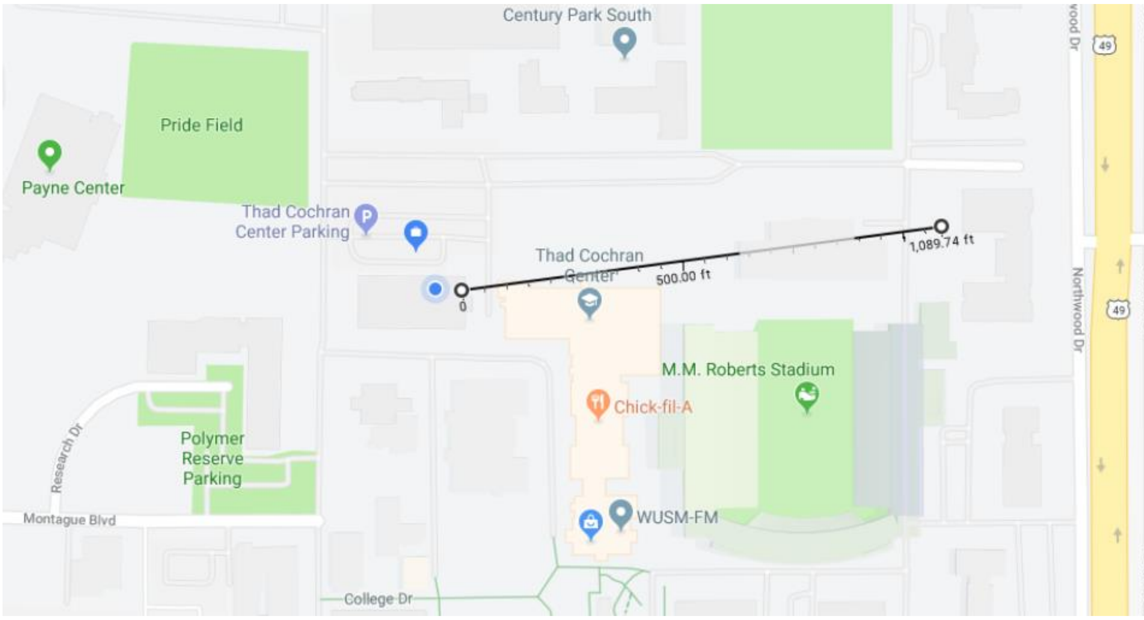

Figure 2. **Campus RF Connectivity Test.** The distance of 1,089 feet was not the maximum the devices could achieve. This was the distance tested within the space available. There was no sign of disconnecting or dropping data packets.

Figure 1A shows the maximum connectivity distance we were able to achieve with the LoRa system at an apartment complex. This distance is the maximal distance we were able to achieve without any data packet loss. Data packet loss would be detrimental to the project, especially if this communication protocol were to be used on multi-million-dollar military aircraft.

Figure 1B shows the maximum connectivity distance for LoRa on the USM campus. The distance was only 235 m. This was the maximum distance we were able to achieve using the LoRa communication method, and still there was data packet loss. This was quite unfortunate; although the bandwidth is not as high as desired, multiple km connectivity was still not achieved.

Figure 2 is the connectivity distance for the P2P RF interface. After three LoRaWAN tests with substandard results, it was decided to try the P2P RF connection method, which provided better results. Two P2P RF interface tests revealed transmission distances over 1,000 feet with no packet loss. Further testing of greater distances with the P2P RF interface were unnecessary, as it was shown that P2P RF was a better solution than the LoRa communication for this particular application. Proving that P2P RF is a better solution may not seem practical without further testing, but given the large margins between the two solutions, this testing was sufficient. The LoRa protocol would typically have connectivity issues over 500 feet, and at those distances, data packet loss was a large issue. With the RF interface, packet loss never became an issue, even at distances over 1,000 feet. There was a space constriction as well. One thousand feet was the longest distance that we could cover without the hazard of moving to public roadways. The only other viable solution was Hub City Dragway, a quarter mile drag strip that measures over 1,500 feet. We were, unfortunately, not able to secure a time and date to test the protocol at the drag strip.

Chapter 5: Conclusions

The experiments performed for this project had varying results. While the connection from transmitter to receiver was acquired, the connection was not nearly as strong as it should have been. With the maximum connectivity distance being approximately 15 km, the idea was to have a remotely accessible vehicle that could be controlled from that distance. However, from the testing it was concluded that the 15-km distance was, in fact, only possible with optimal conditions. This distance does not consider a crowded city with multiple layers of interference. In practice, we were only able to obtain a connection of 606 feet at an apartment complex (Figure 1A), and 770 feet on the USM campus (Figure 1B). The experiment was conducted again using the P2P RF interface, and the distance achieved was 1,089 feet (Figure 2). This is slightly better than the LoRa technology, however, still nowhere near the 15 km of which the technology was said to be capable. In conclusion, the experiment needs to be repeated with a much larger budget. Larger transmitters, receivers, and antennas may allow the technology to reach the 15-km transmission distance. With a higher budget and better equipment, the practicality of this project can be increased as the improved technology allows for connectivity closer to the specified maximum distance.

References:

1. Carter, Mark David. "Patent US6283220 - Remote Control Vehicle." *Google Patents*. Google, Web. 17 Apr. 2017.
2. Adelantado, Ferran, Xavier Vilajosana, Pere Tuset-Peiro, Borja Martinez, Joan Melia-Segui, and Thomas Watteyne. "Understanding the Limits of LoRaWAN." Web. 17 Apr. 2017.
3. Mcgrew, David. *Low Power Wireless Scenarios and Techniques for Saving Bandwidth without Sacrificing Security*. Web. 17 Apr. 2017.
4. Song, Qipeng, Loutfi Nuaymi, and Xavier Lagrange. "Survey of Radio Resource Management Issues and Proposals for Energy-efficient Cellular Networks That Will Cover Billions of Machines." *EURASIP Journal on Wireless Communications and Networking* 2016.1 (2016): Web. 17 Apr. 2017.
5. Petäjäjärvi, Juha, Konstantin Mikhaylov, Rumana Yasmin, Matti Hämäläinen, and Jari Iinatti. "Evaluation of LoRa LPWAN Technology for Indoor Remote Health and Wellbeing Monitoring." *International Journal of Wireless Information Networks* (2017): Web. 17 Apr. 2017.
6. Langer, Dirk, and Charles Thorpe. "Sonar Based Outdoor Vehicle Navigation And Collision Avoidance." *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems* Web. 18 Apr. 2017.
7. Hollowbush, Richard R. "Patent US5059946 - Ultrasonic Obstacle Detector." *Google Patents*. Google, Web. 18 Apr. 2017.
8. Shyy, Yeu-Hwa. "Patent US5262837 - Laser Range Finder." *Google Patents*. Google, n.d. Web. 18 Apr. 2017.
9. Newman, David L. "Patent US20140316614 - Drone for Collecting Images and System for Categorizing Image Data." *Google Patents*. Google, Web. 18 Apr. 2017.
10. Drew, Christopher. *Drones Are Playing a Growing Role in Afghanistan* (2010): 20 Feb. 2010. Web. 18 Apr. 2017.
11. Iqbal, Umair & Irtiza, Syed & Rehman, Zia & Jmail, Moshsin. (2015). *Long Range Radio Modules for Model Unmanned Aerial Systems: A Short Comparison for Disaster Relief Applications*. Web. 15 Jan. 2019