GPS/GSM Based Tracking System for the Recovery of High Power Model Rockets

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Abstract—In high-school IGNITE classes during high-power rocket flights, the rockets, sometimes traveling as high as 13,000 ft, are frequently lost. Antiquated visual tracking methods have been proven ineffective at rocket recovery, and, as some of the rocket parts are reusable, the failure to retrieve rockets can cost classes up to hundreds of dollars a year. To solve this problem, an electronic tracking system has been developed utilizing a microcontroller (Arduino Uno) with two RF XBee devices incorporating a GPS chip. The 3-D coordinates of the rocket can be received through the GPS and transmitted via radio waves to a computer. Through this method, the location of the rocket can be sent to the user continuously, allowing him or her to know the bearing of the rocket at almost all times and greatly improving the retrieval rate of said rockets.

Index Terms—Arduino, GPS, GSM, High-power Rockets, IGNITE, Recovery Systems, Tracking

I. INTRODUCTION

Project-based learning and STEM schools are attempting to increase student buy-in on the critical skills they need, such as problem solving, to prepare them to be successful in the future. A sub-set of both project-based learning and STEM is a rocketry class called IGNITE. In high school IGNITE classes, students design and build their own high-power rockets during the second semester. Unfortunately, rockets are frequently lost after launch due to a variety of factors, including, but not limited to: the stability of the rocket’s flight, how the recovery sequencing occurs, and the winds at certain altitudes. Even with human “trackers” positioned on hilltops to aid with tracking, the rocket can easily escape visual surveillance after reaching heights from 5,000 ft to 13,000 ft.

II. CRITERIA

To solve this problem, an electronic system has been developed that will monitor the position of the rocket during flight. The system will consist of an XBee RF wireless receiver, an XBee RF wireless transmitter, an Arduino Uno, and a battery. As frequently as possible, XBee transmitter will send the longitude, the latitude, and the altitude via radio waves to the XBee receiver. The information will be displayed on a serial monitor on the computer.
The system must be able to withstand the initial Gs experienced from the launch acceleration, (around 10 - 12 Gs, approx. 100 - 120 m/s²) and potentially, the impact of a crash-landing. However, should the system fail as a result of a crash-landing, the last coordinates sent by it (immediately before the crash-landing) should be enough to pinpoint the location of the rocket.

The system will need to be small, light, relatively inexpensive, easy to use, easy to work on, and easy to install into the rocket.

One potential problem that could occur when the rocket is near landing is that it may encounter objects in its surrounding environment that could interfere with the radio waves. To counter this, the micro-transmitter will be designed to send the data at a rate that is rapid enough to offset the blockage so the data will be received in the most immediate time period before the interference occurs.

III. LITERATURE REVIEW

In recent years, the GPS has been employed to successfully track a plethora of objects from animals from otters [4], brown bears [5], sable antelopes [6], and moose [7], to a variety of fleet vehicles [10, 13, 19]; in addition, it has also been chosen to assist in rangeland management [12], to track patients with mental conditions such as dementia [16] or with physical disabilities [20], to increase the comfort of driving in automobiles [17], to prevent the theft of automobiles [13], and to create security systems [21]. The ability to track through less than ideal conditions of wet or dense terrain [4, 5, 7], along with the shrinkage of GPS units through the advancement of technology (some weighing at most 12 g) [14], enhances the operability of it and makes it an ideal device to locate most rapidly moving entities.
Most of the tracking devices that have been developed generally revolve around the following basic design: a GPS tracker [10], a device that is used to transmit the data to a designated receiver, and a power supply. Most also incorporate some form of a microcontroller [20], which processes the data measured or received [15], and an antenna to enhance the transmission and the receiving of data. Every subsequent tracking device that has been developed is based on ameliorating the previous ones in areas such as, but not limited to: increasing the accuracy of the data (by limiting the device’s impact on the behavior of the target object), increasing transmission range, shrinking the size and weight of the device, designing the system so that it consumes less energy, and decreasing the cost of the system [4, 5, 11, 14].

Each of these tracking devices that have been developed mostly employ one of the following methods to transmit their data: sending it as a SMS message to a predetermined cell phone through the GSM network [5-7, 13, 15, 18-20], sending the data utilizing a radio-based transmission system through narrow-band VHF or ultra-high frequency (UHF) [11], or using the General Package Radio Service (GPRS) to send the packets of data [19-21].

The Arduino is an open-source microcontroller that allows for the average electronics hobbyist to explore more about electrical engineering. The programming language for the Arduino is based on the “C” language. Hundreds of projects have been developed utilizing the simplicity of the Arduino hardware and software, giving rise to a new generation of novice engineers. With such a variety of possible projects, the Arduino can be adapted to almost any environment, from high-profile research projects to the average classroom setting, the latter of which is what trying to be accomplished here. Not only is the Arduino itself such an adaptable piece of hardware, it also comes in an assortment of different boards. The particular board that this tracking system uses is the Arduino Uno: the first Arduino ever developed [1].

The use of the Arduino has greatly decreased the expense of high school science experiences. Costing around $20 to $30 [1], high school classrooms could easily purchase Arduinos in bulk. Students are able to design and program a variety of lab equipment materials [3, 9] that may have been unavailable or in limited quantities before. Not only is the Arduino easy for students to master, but it also has a growing community that can serve to facilitate the students’ learning of the Arduino.

High school rocket classes launch high-power rockets, capable of reaching 13,000 ft and more. Finding them after landing parallels the tracking of the aforementioned animals, vehicles, and people. The principles of geolocation could easily be applied to the tracking of rockets during flight. Through the operation of an XBee RF wireless transmitter, an XBee RF wireless receiver, and an Arduino Uno, an “Estes Leviathan” [12] rocket powered by a G40-7 motor will be tracked to test the proof of concept. With successful implementation of the proof of concept, a similar system can be designed and built by students in the class to help ensure recovery of the launched rockets.

IV. PROPOSED SYSTEM

The system will consist of an Arduino Uno, an XBee RF wireless transmitter with a GPS chip to be placed in the payload of the rocket, an XBee RF wireless receiver to be connected to a computer, and a battery. The GPS will receive the three-dimensional coordinates of the rocket (longitude, latitude, and altitude). Subsequently, the Arduino Uno and XBee transmitter combination will send the data via radio waves to the XBee receiver. This system will repeat the process through a loop until the power becomes unavailable or the system is retrieved. The total weight and diameter of the system will be approximately 6.66 oz and 2.25 in, respectively.

Fig. 6. A basic overview of the independent components of the proposed system.
V. PROGRAMMING

![Arduino Code Snippet]

```cpp
#include <SoftwareSerial.h>
SoftwareSerial gpsSerial(2,3);
#include <core4.h>
const int abs
const int read
#define GGA gps(GPRMC) // GPS data connection to GPRMC sentence type

void setup()
{
    Serial.begin(9600);
    gpsSerial.begin(9600);
    delay(150000);
}

void loop()
{
    if (gpsSerial.available() > 0)
    // read incoming character from GPS and feed it to NMEA type object
    if (gps.decode(gpsSerial.read()))
    // full sentence received
    Serial.println (gps.sentence());
    Serial.print ("GGA, ");
    Serial.print (gps.datetime());
    Serial.print (" Number of terms = ");
    Serial.println (gps.terms());
}
```

Fig. 8. Example of the receiving part of the code.

VI. SIMILAR SYSTEMS

A similar system to the one that is being constructed is the “Big Red Bee 900.” This system operates with a GPS receiver connected directly to a 900 MHz transmitter that sends GPS position signals to a receiver over a 900 MHz spread spectrum transmitter. The entire package costs about $430. This expense is cost-prohibitive in a public school setting, but if the system being created in this project could be modified with increased transmission rates to that of the “Big Red Bee 900,” this expense could be nullified.

Another option would be to package a GPS receiver with an XBee wireless transmitter onto an Arduino microcontroller. The difference is in the transmission. An XBee uses the 900 MHz transmission frequency as well, but it has limited range, particularly in a cluttered environment such as the Texas hill country.

These two other solutions, each with their problems, led us to the XBee RF solution.

VII. METHOD

A. Construction

An Estes Leviathan rocket [12] was assembled to test the tracking device. The Leviathan was selected for its 3.0 in diameter, suitable to house the 2.25 in diameter tracking system. The unit was packed in “pluck” foam and placed behind a balsa wood bulkhead to secure it during the flight.

![Leviathan Rocket]

Fig. 9. “Pluck” foam used to protect the payload against any disturbances during the flight of the rocket.

![Leviathan Rocket]

Fig. 10. The Estes Leviathan rocket used to test the proof of concept.
Utilizing a G40-7 motor, rocket modeling software indicated that 10 - 12 Gs would be generated. This acceleration is similar to that of the larger rockets constructed in the IGNITE class.

B. Data Collection

Please see the appendix for the data table.

Fig. 11. The Estes Leviathan rocket lifting off.

C. Data Analysis

Given the caliber of the equipment used in the construction of the tracking device, the accuracy of the data collected met the expectations of the project members. The following pictures display the locations given by the data collected.

Fig. 12. The location of the rocket before launch.

Fig. 13. The location of the rocket after launch.

VIII. PROBLEMS ENCOUNTERED

This project consisted of three different phases. The first phase consisted of a dual GPS/GSM shield from DFRobot. GPS coordinates would be received and transmitted to a cell phone via a Short Message Service (SMS) message (text message). This first attempt failed because of the GPS’s and GSM’s inability to communicate with each other, although both devices were able to operate independently of each other.

This failure led to the second phase, which consisted of independent GPS and GSM components from Sparkfun. Even though this system functioned perfectly, it could not operate without being tethered to a computer.

Eventually, it was decided that hardware from XBee would solve the issue. Two XBee devices, an XBee RF wireless transmitter and an XBee RF wireless receiver, would be utilized to track the rocket.

The largest problem so far has been with the shield: it was not able to connect to the GSM network. Although it could retrieve GPS data, it could not be sent anywhere. Several different attempts were made to connect with the GSM network including utilizing different SIM cards (from different cell phones), operating with alternative programming, changing locations (including locations miles away) and converting GSM network frequencies. All of these attempts failed. As a final effort at troubleshooting, a separate GSM-only shield was used instead of the combined GPS/GSM system. After its success, it was decided that a GPS-only shield would be used to see if it could receive GPS coordinates at a constant rate. This technique proved to be fruitful as well. With the ability to receive text from a separate, GSM-only shield and the ability to receive position from a separate GPS chip, it was discovered that the issue was with the hardware. The original shield was returned, and independent GSM and GPS devices were ordered. No problems were encountered while the Estes Leviathan rocket was being constructed.
IX. RESULTS

The rocket was built and readied for flight quickly, but creating the electronic system was quite challenging. The project members were able to learn the basics of the Arduino Uno’s functionality. As the initial shield was worked on, however, several problems came up. The GPS/GSM quad-band shield that was supposed to be mounted on the Arduino Uno from DFRobot refused to cooperate with the program that was uploaded to it [2]. The project was set back nearly three weeks. The shield would, from time-to-time, give indications that it was attempting to join the network, but it could never fully connect.

It was decided that alternative hardware would be used. Initially data was not able to be received at all, but with some effort, online tutorials, and product support, a GPS location was finally retrieved utilizing the Arduino microcontroller and a GPS shield from Sparkfun. Additionally, text messages were able to be sent via an independent GSM shield. This gave us clear indication that the issue resided with the DFRobot hardware [2]. The hardware from DFRobot was returned, and new hardware from Sparkfun was ordered.

Most of the subsequent problems seemed to surround power demands. The system was able to perform while it was connected to a computer via USB, although once it was disconnected, it would fail. The system was then connected to a stand-alone power supply as a possible solution, but that too failed.

The successful launch and recovery of the system with an XBee transmitter yielded success. With consistent data during flight, the system also negates the need for an altimeter, which is a common device used in model rocketry for flight data collection. The key will be in flight data.

X. CONCLUSION

The Arduino backed GPS shield receivers with GSM shield transmitters from Sparkfun and DFRobot do not appear to be the solutions at this time. The systems are, at best, unreliable. The system was not able to function without it being tethered to a computer via a USB connection. Further research needs to be accomplished to determine the source of the issues. It is possible that the computer provides the serial port necessary to complete the programming. It is also possible that the computer is providing additional power requirements. Both of these issues require further investigation. Perhaps, an XBee RF transmitter would be a solution if line of sight issues could be solved.

The XBee solution seems to be the way to go. As other commercial devices using XBee technology already exist and function appropriately, it seems reasonable that creating one is a path to success.

XI. FUTURE WORK

With the successful launch with the XBee RF transceiver, it is evident the system is viable. The largest question is if the system will transmit during flight. Due to the limited range (400 feet) of the available equipment, no data was received during the actual test flight. An obvious extension would be the implementation of a higher quality (and hence longer range and more expensive) XBee system. With a longer range system, it may be possible to eliminate another electronic component, the altimeter, which is required by those who write the curriculum.

With the proof of concept achieved, additional research could be applied to almost any other field that requires some form of tracking. Anything with this project that reduces size, cost, or programming difficulty could be targeted for improvement in the future. For example, Arduino has different sizes of its microprocessors. One of them, an Arduino Nano, is only about one inch across and about 2.5 inches long. This size of a system would make fitting one of these trackers into very small rockets, such as...
those that parents build and launch with their children in a local park, relatively simple. Continued research on cell phone tower coverage would also be up for consideration. Data is lacking on raw GSM systems and how they interact with a given network. Research on 2G, 3G, and even 4G systems, their various coverages, and their interactions with GSM systems would dramatically increase the gamut of equipment that could be used to construct tracking systems. Furthermore, the ability of these signals to penetrate low lying area (between hilltops) or through dense foliage could be studied.

### APPENDIX

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**REFERENCES**

**A. Technical Data Sheets**


**B. References**


