Ballistic Parachute Recovery System for Unmanned Aerial Vehicles (UAVs)

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Morgan, Andrew
Youngstown State University
1 University Plaza
Youngstown, OH 44555
asmorgan@student.ysu.edu

Chapman, Richard
Auburn University
Auburn, AL 36849
chapmro@auburn.edu

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Abstract

As microcontroller technology continues to grow and develop, Unmanned Aerial Vehicles (UAVs) are experiencing explosive growth in civilian, commercial, and governmental sectors. To help maintain a safe environment for all directly and indirectly involved, the Federal Aviation Administration (FAA) has implemented regulations on UAVs to enhance safety and help prevent airborne collisions. Current requirements and regulations limit hobbyists and professionals while behind the controls of an unmanned aircraft. To help prevent failures in UAV operation, a ballistic parachute recovery system monitors several components of real-time flight, that will ultimately help ensure a safe airspace and operation environment.

1 Introduction

Unmanned Aerial Vehicle (UAV), or often referred to as Unmanned Aircraft Systems (UAS), registration officially opened on December 21, 2015 for personal hobbyists. After two days of registration, the database contained 45,000 aircrafts dedicated and designed for personal use. This mandate was set forth by the Federal Aviation Administration (FAA) after incidents of drones falling from the sky into airplanes, crowded sports games, and national parks. Failure to register a personal drone weighing between 0.55 lbs and 55 lbs could detail a fine of up to $27,000.

Through a severe influx of drones becoming available to the everyday consumer, other regulations were set forth by the FAA to maintain a safe environment for flight within public air spaces. Not only does the hobbyist and professional have to register the aircraft, but must also comply with federal flight mandates. Failure to comply could potentially result in fines and/or imprisonment. It is of utmost importance that aircraft are flying legally and safely in any given airspace.

This paper will explore the build and design of a ballistic parachute recovery system. This system will monitor several variables in real-time to determine whether or not the aircraft is operating in a safe environment. The elements observed are main battery voltage, current GPS coordinates, and current acceleration. If the system determines that the aircraft is operating in an unsafe environment, the recovery system will cut main power and deploy a ballistic parachute to guide the aircraft safely to the ground. The software and hardware design will be presented in the scope of this paper.

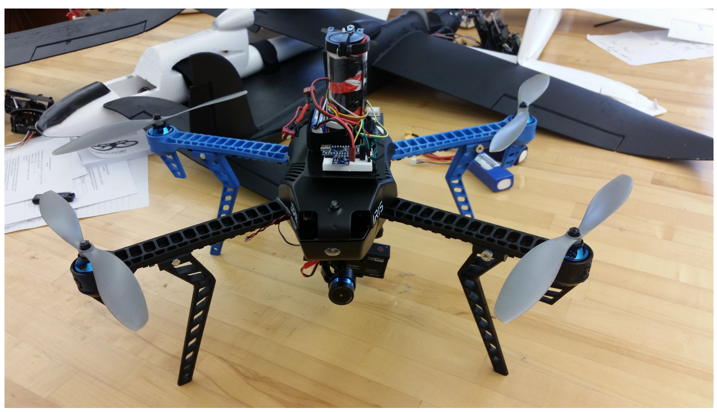

Figure 1: Recovery Parachute attached to Quad-Rotor System

2 Literature Review

The concept of recovery systems in manned and unmanned aircraft has been around for decades. From the very beginning of flight, research in recovery systems has been of great interest to help maintain safety in various aircaft.

Recovery systems are continuing to change and evolve according to the task at hand. Utilizing a net-recovery system on fixed wing UAVs continues to be studied. Net-recovery practices are used in order to make a UAV recover precisely along the predicted glide path. Presented as a virtual mesh, the net coordinates how the UAV should approach to land properly. [3] New concepts of quadcopter (quadrotor) designs do not have the capability of gliding to the ground like fixed wing aircraft. Basak and Prempain explore a method of recovery for a failed UAV actuator. Instead of building an independent system for recovery, all monitoring and reaction was accomplished internally. According to the given situation, the recovery system will take over and coordinate motion of the UAV. This work looked at the failure of one of four motors, later determining it was possible to maintain safe flying stability through the thrust of three motors working together.[2]

With any sort of recovery implementation, detecting the state of the the aircraft, whether safe or unsafe, is vital to proper use. When UAVs enter an unsafe flight state, the likelihood of an accident occurring without proper controls increases drastically. Huan et. al continued by exploring ways to detect current states of an aircraft. [4]

A large interest in recovery design has been to implement a parachute system. Manned aircraft currently utilize such a unit, thus an unmanned aircraft could potentially implement the same. Different types of parachutes perform differently under given conditions. Larger parachutes have a pilot chute. This pulls the main parachute out of its container. [7] Other parachute shapes and sizes are used according to the size, weight, and conditions the aircraft is operating in. [5] A parachute system works well under given climate conditions. Shao et. al evaluated a model of the UAV-Parachute system, with wind fields and a control strategy for recovery. [6]

3 Current FAA Regulations

The FAA currently divides UAV operation into three separate categories. These categories dictate specific regulations to a given individual or organization. In order to be considered for an operation other than for hobby, formal FAA approval is required.

Public Operation: utilized by government own/run organizations
Civil Operation: intended for commercial/business use
Hobby Operation: operated for hobby/pleasure

3.1 Public Operation

In order for an aircraft to be classified for use in public operation, the aircraft must be owned and operated by a governmental organization. Whether an operation qualifies under this domain is determined on a flight-by-flight basis.The considerations in determination are aircraft ownership, operator status, purpose of flight, and persons on board the aircraft. Public universities can qualify under this section if used for the university's own operation or research. In order to fly in civilian airspaces, universities need a Certificate of Waver or Authorization (COA) presented by the FAA. This document outlines regions if airspace, periods of time, and special conditions where aircraft can and cannot fly. The COA helps ensure that aircraft are not operated in populated areas and have proper handling/safety measures.

3.2 Civil Operation

Any operation that does not meet criteria for public operation and is not maintained by a single individual for hobby use is classified under the civil operation domain. Since this is applicable to all non-government organizations, civil operation often falls under commercial use via utilization by a business. Civil operation regulates several variables such as speeds and altitudes of unmanned flight. A UAV in operation must not reach an altitude higher than 400 feet unless close to a stationary structure, and must not exceed a ground speed of 100 mph (87 knots). Other restrictions include a weight limit of 55 pounds, governmental registration of aircraft, and Visual Line-of-Sight (LoS) requirements.

Beginning August 29, 2016 a "person operating a small UAS must either hold a remote pilot airman certificate with a small UAS rating or be under the direct supervision of a person who does hold a remote pilot certificate (remote pilot in command)." [1] In qualifying for a remote pilot certificate, a person must either pass an initial aeronautical knowledge test or hold a part 61 pilot certificate. Through this certification, it is possible for non-governmental organizations to own and operate UAVs for profitable use.

3.3 Hobby Operation

Hobby Operation is often referred to as Model Aircraft Operation by the FAA. This domain includes operations that are for hobby and recreational use only. An outline of safety guidelines is presented by the FAA to help promote safe flying practices among individuals. In this domain, an aircraft more than 0.55 pounds and less than 55 pounds requires registration. Aircraft less than 0.55 pounds does not need registration, and aircraft above the 55 pound limit cannot be classified for Hobby Operation. Other FAA regulations include but are not limited to:

- Operator must fly below 400 feet and remain clear of surrounding obstacles
- Aircraft must remain well clear of and do not interfere with manned aircraft operations
- Aircraft cannot fly within 5 miles of an airport unless you contact the airport and control tower before flying
- Aircraft cannot fly near people or stadiums/public events

4 Design

The design of the ballistic parachute recovery system is presented in two sections, Hardware and Software. The hardware used for this design is readily available from several retailers. The software process is described according to implementation of the design.

4.1 Hardware

The recovery system design implements several hardware units that allow the system to determine GPS coordinates, remaining battery voltage, and acceleration. If the system determines any of these values to be inadequate, the recovery system cuts power and takes over.

The hardware described in this section primarily refers to the components used in this recovery system operated by software. The parachute utilized for recovery was a Mars Mini Ballistic Parachute. The parachute is deployed by servo motor controlled door. The parachute fabric is launched outward by an internal spring and plunger mechanism. Resetting the unit is possible for quick testing.

The parts used to construct the recovery system are listed below:

Table 1: Parts List

Make	**Model**	**Summary**
Arduino	Nano	The arduino nano is used to connect the system together and control all components. This microcontroller provides enough processing and I/O for proper implementation.
Adafruit	GTPA010	This component will serve as the GPS signal device for the system. This is how the system can determine if the aircraft is outside a given airspace. Real time data is transmitted by National Marine Electronics Association (NMEA) data via RS232 serial communication.
Turnigy	Micro Servo TGY-90S	The servo motor will act as a release mechanism for the spring loaded parachute. When deploying the parachute, the servo will be opened and detached.
Sparkfun	ADXL330	The accelerometer will be used to measure forces acting upon the aircraft. If the forces are 0 in all directions, then the aircraft is in free fall.
Uxcell	25V Votlage Sensor	The uxcell sensor will determine instantaneous voltage from the main battery supply. If the battery falls too low, the recovery system will cutoff power and take over. Voltage sensor implements a voltage divider for safe voltage reading.
Uxcell	5V Relay	The relay will be used to cut main power to the aircraft when operating conditions are inadequate for flight.
Turnigy	7.4V LiPo	A LiPo battery is used to power the recovery system independently from main power.

The recovery system is controlled independently through the use of an Arduino Nano microcontroller by a LiPo battery. This microcontroller unit provides 14 Digital Input/Output Pins, 8 Analog Pins, 5V power source with a 16 MHZ Clock and 2Kb of SRAM. Through this unit, all monitoring and decision making processes are completed. Each hardware component is connected to the microprocessor accordingly:

Accelerometer - The accelerometer is connected via analog pins on the microcontroller. Acceleration components in x, y, and z directions are read according to voltage values generated by the accelerometer. Since the accelerometer module does not require much current, analog out values were a sufficient source of power.

GPS - The GPS module is powered through the voltage supplies and communicates over a "Software Serial" connection on the microcontroller's Digital I/O pins. This transmits NMEA data via a RS232 serial connection.

Voltage Sensor - The voltage sensor connects to an analog pin on the microcontroller. The voltage sensor unit acts as a voltage divider to provide safe voltage values to the microcontroller. The internal resistor values are 4:1, providing a 5x voltage drop.

5V Relay Module - The relay module is activated by a 5V digital signal from the micorcontroller. This particular relay was "Active HIGH", providing that a HIGH 5V signal to the module activates the internal switch.

Servo Motor - The servo motor is connected via a Pulse with Modulation (PWM) signal from the microcontroller's digital pins. To save energy for the recovery system, the servo motor is set to close initially and then virtually detached from the system. This saves energy while the pressure of the parachute requires the door to remain closed.

The figure below presents the overall design schematic of the ballistic parachute recovery system:

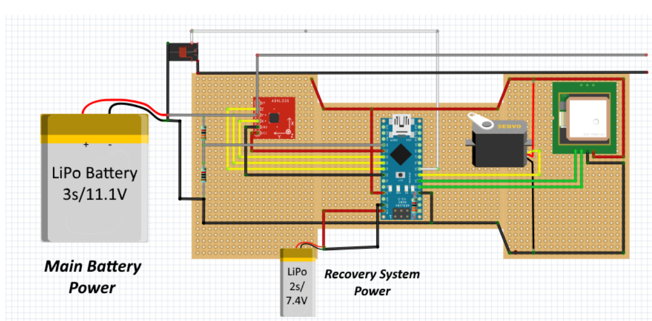

Figure 2: Breadboard Schematic of Complete System

4.2 Software

The software design for this system was built to constantly monitor the three elements of determining aircraft failure: main battery voltage, free fall, and beyond Line-of-Sight (LOS) distance. Through the hardware components previously described, it is possible to obtain real-time values of the components in which need monitored.

When monitoring values, specific calibration is needed for proper use as a recovery system. The accelerometer values need to be set to detect free fall, the voltage sensor must be calibrated to proper cutoff voltage of motors, and the GPS must obtain current telemetry with intended size of airspace. Once these components are set, the UAV will be available for flight. The software design flow is outlined in the figure below.

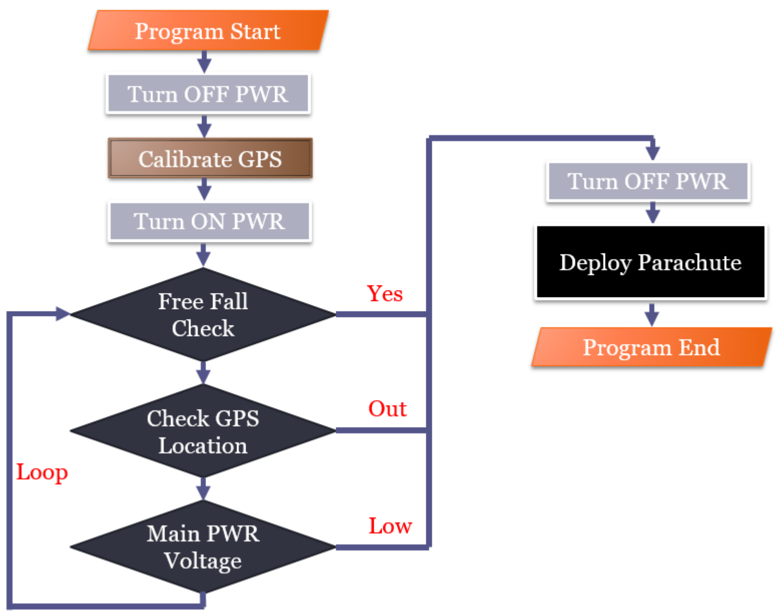

Figure 3: Software flow chart of Recovery System

4.2.1 GPS

The GPS unit is constantly updated from provided National Marine Electronics Association (NMEA) data. This information presents current longitude and latitude coordinate location of the aircraft, with additional information such as elevation and direction of motion. The Adafruit GPS unit communicates via RS232 serial connection to the Arduino Nano at a baud rate of 38400 Bd. There are several messages associated with NMEA data, but only current longitude and latitude are monitored and record.

To help comply with current FAA regulation the operator, and/or flight assistant, must have a complete LOS view of the aircraft while in flight. To ensure that an aircraft, primarily fixed wing gliding beyond LOS, is operating in a secure and controlled environment, the aircraft will be operational under a given airspace determined by the GPS. If the the aircraft exceeds an allotted airspace barriers determined before flight, the recovery system will take over and cut power to the main system. Once it cuts power, the recovery system will deploy the parachute and land safely.

This concept is illustrated in the figure below:

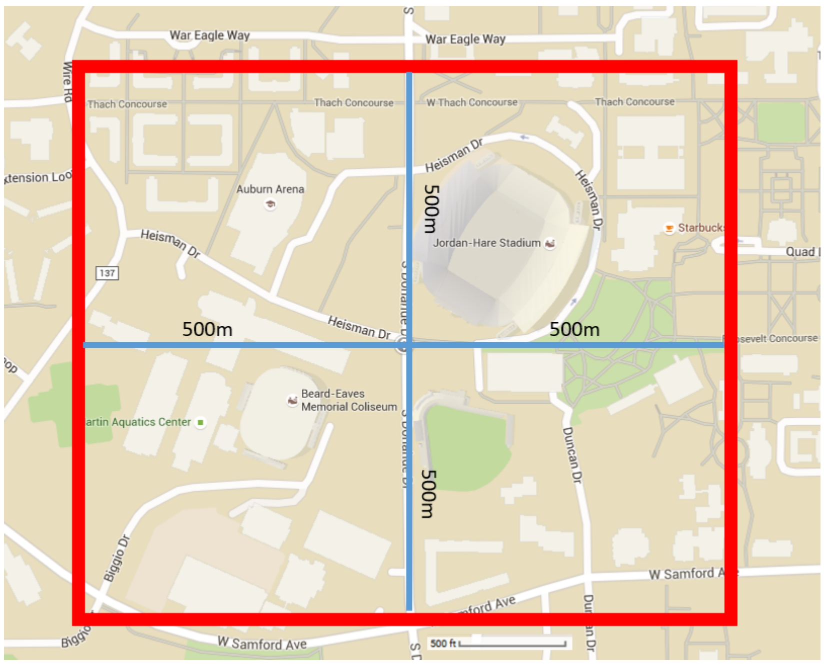

Figure 4: Designated 1000m Airspace over Auburn University

4.2.2 Voltage Sensor

The voltage sensor polls values continuously from the main battery source. Brushless DC Motors often used on UAVs are voltage dependent, that is the voltage of the source primarily runs the motors. Lithium Polymer (LiPo) battery technology is typically used in hobby based UAV aircraft. These batteries have properties consisting of constant voltage until end of charge. Once the charge begins to reduce, the battery voltage falls rapidly.

After determining the voltage remaining in the battery, the recovery systems determines if the state of the aircraft is adequate for safe flight. If it is, the system continues to monitor. If the voltage of the main battery reduces to such an inadequate voltage, the recovery system takes over. This process cuts off power to the aircraft via the relay, and deploys the parachute for a safe landing.

Addressing real-time battery voltage is most applicable to multi-rotor systems. Fixed-wing units have the capability to glide when powered down mid-flight. Unlike the fixed-wing system, multi-rotors need to power all motors for stable flight. By monitoring battery voltage it is possible to determine a potentially unsafe flying condition.

4.2.3 Accelerometer

An accelerometer attached to the recovery system constantly monitor forces exerted on the aircraft. The goal of the accelerometer is to monitor the UAV for detecting free fall. While other forces acting upon the UAV may be useful for determining orientation and movement, the accelerometer needs to monitor the instance in which a UAV may be in an unsafe state. In the case that the operator loses control of the aircraft, where many UAVs cannot recover from free fall accelerations, the recovery system deploys a parachute and cuts power to the main controls via the relay. The accelerometer has successfully detected free fall when the the aircraft is experiencing 0 acceleration in x, y, and z directions.

Similar to the reason for monitoring the main battery voltage, this approach is more applicable to multi-rotor systems. When a fixed-wing UAV is powered down mid-flight, it is possible for that unit to potentially reach the ground safely and securely. Unlike that of a fixed-wing system, multi-rotors to not maintain any sort of stable flying paths and lose elevation fairly quickly. This implementation is focused to address this issue unsafe free fall conditions.

The complete parachute design is provided in the figure below:

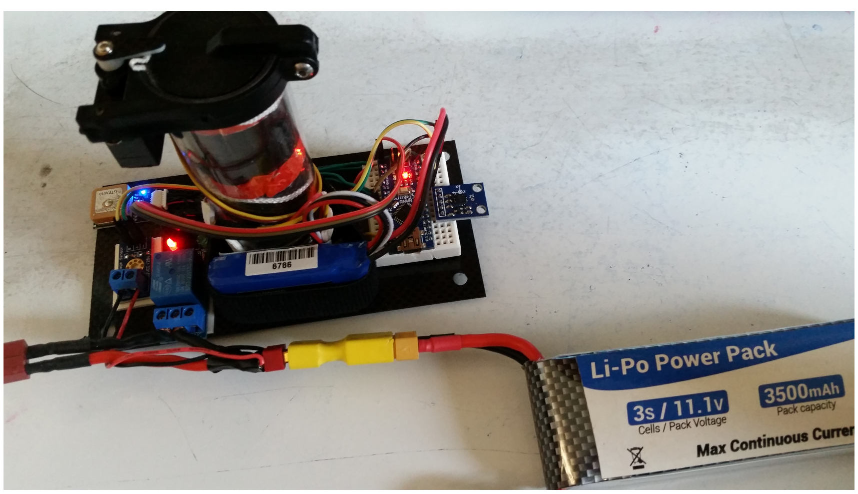

Figure 5: Complete Ballistic Recovery Parachute Module

5 Conclusion

The ballistic parachute recovery system design presented in this paper provides safer operation for UAV systems. With availability for utilization on any UAV, implementing this independent monitoring and recovery system presents a potentially safer environment for all that are involved.

Through the use of several hardware components, it was possible to monitor and react to potentially unsafe conditions for a given UAV. GPS coordinates, current battery voltage, and current acceleration were all considered when determining the state of aircraft. If values recorded were sufficient for safe flight, the parachute was deployed and main power to the aircraft was terminated. All tests were concluded successful for each individual component.

Future work for this particular recovery system would include additional testing and aircraft integration. While this unit was constructed and tested for individual component functionality, the system did not undergo tests on an aircraft. By design of this project, transferring this recovery system to a single unit for easy addition to current UAV designs is important to proper integration into the civilian market. Additional testing and integration onto an aircraft would allow this system to be implemented on any design of UAVs.

This recovery system addresses several concerns for UAV pilots operating in a provided airspace. As the sales of hobby UAVs continue to grow, it is important to provide a safe environment for those directly and indirectly involved in flight. As the designs of unmanned aircraft continue to develop, it is important to consider safety as the number one priority. The implementation of this recovery system on UAVs makes these aircraft one step closer to becoming safe for users of all experience levels.

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