University of California, San Diego
AIAA – AUVSI

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Abstract

This paper describes the accomplishments of the student led team of interdisciplinary engineers that has designed a system in order complete the mission of fully unmanned aerial reconnaissance for victory in the AUVSI Student UAV Competition. UCSD's fixed-wing entry consists of three major subsystems comprised of airframe, autopilot, and payload which were managed by three respective groups within the student team. Components of the system were mostly commercially available while others were fabricated. The spirit of the competition was incorporated into the design criteria as the mission was considered; a simulation of field applications such as battlefield surveillance, homeland security, fire management, or even agricultural applications. These considerations are evident in features that were scaled to create a robust package. Safety measures were incorporated into individual systems for the safety of operators, staff, and spectators. Dual redundant recovery/control systems have been implemented as well as the required fail-safe mode per competition rules in the unlikely event of catastrophic failure.

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Mission Overview

The AUVSI Student UAV Competition specifies for the systems engineering of a **Low-Altitude Unmanned Aerial Vehicle-Reconnaissance Demonstrator**. Given constraints such as take-off and landing zones, altitude, and navigational waypoints, the UAV is to carry out its mission while maintaining its boundary within these mission limits. The competition does not require but suggests a fully autonomous vehicle from take off to landing, while maintaining the ability to switch to a radio controlled mode by a vehicle operator.

Reconnaissance of ground targets will consist of locating and assessing man made targets within a target area. GPS coordinates as well as the number of targets and their orientation are to be acquired by the UAV. Dynamic re-tasking will be required to track down emergent and pop-up targets.

Total mission time will be less than 40 minutes and the UAV will weigh less than 55 pounds. Safety will be strictly enforced and the UAV is to comply with the 2006 Official Academy of Model Aeronautics National Model Aircraft Safety Code as well as the completion of an inspection by designated competition safety inspectors. The mission profile can be found in **Appendix 1**.

Design Overview

The UCSD Student UAV Concept's backbone consists of an RnR APV-3 airframe coupled with Cloud Cap Technology's Piccolo autopilot system. The UAV will take off and navigate through a specified search pattern, then land under manual control.

A removable payloads package under the UAV will house all necessary hardware and power supplies to carry out the reconnaissance of ground targets. Installation of an on-board computer will allow the UAV to autonomously recognize targets which will be recorded on a hard drive and relayed to the ground station for live view of the field. See figure 4 for a detailed schematic of the payloads.

The payloads package will also house a Sony FCB-EX78P block camcorder installed in a custom fabricated 2-axis gimbal. The two servos that operate the gimbal are connected to the autopilot which will orient the camera straight down for an undistorted view of the field and accurate GPS coordinates of the targets.

Airframe

Vehicle Selection

There are many factors governing the selection of a suitable air vehicle for the 2006 AUVSI UAV challenge. The 2005 challenge illustrated that lighter, hobby quality airframes are far from ideal as autonomous vehicles, especially with substantial wind during the summer at Webster airfield. The airframe needs to be both stable as well as carry a high wing loading. The aircraft should be able to comfortably accommodate a payload greater than 5 kilograms allowing for future expansion. A large airframe also allows distancing of different antennas, increasing the ability to carry multiple wireless systems. Endurance is also desirable for an autonomous aircraft as it allows long flights while training the aircraft.

RnR APV-3 composite airframe

The aircraft selected was the RnR-APV-3. This aircraft met and exceeded the conditions described above. The platform was designed as an autonomous vehicle capable of carrying a 30+lb payload and is capable of 8+ hours of flight. This aircraft has had a successful track record, with many aerospace companies and researchers selecting it as their vehicle of choice. At an empty weight of 30lbs and a large air-speed envelope, this airframe will have few problems flying autonomously in windy conditions.

Autonomous Benefits

A major benefit of the APV-3 airframe is its wide use in autonomous flight with the chosen autopilot. The autopilot maker, Cloud Cap Technology, uses the APV-3 platform as their platform of choice for autonomous research and testing. This guarantees an easy integration of the autopilot in the platform, allowing us to perform autonomous flights quickly.

Fabrication

The airframe was sourced from RnR Products in Milpitas, California; it retails for $15,500. Since this was more than the entire budget; the team had to explore other possibilities. Richard Tiltman of RnR products sponsored the UCSD team by donating a blemished fuselage shell. The team fabricated the rest of the aircraft, including all of the flight surfaces and landing gear. The entire airframe was structurally engineered to FAA experimental aircraft specifications. The cost of assembly dropped dramatically to $3,000 for the entire aircraft. The wings, rudder and horizontal stabilizer were fabricated from foam core carbon/fiberglass. This gave an aerodynamically identical aircraft, tougher and more durable than the actual APV-3 from RnR Products. The airframe is finished with a Fuji 86BTI, 86cc two cycle motor fitted with a spring starter. This motor has an abundance of power and is extremely reliable. The spring starter gives the benefit of eliminating additional field equipment to start the motor. With an internal fuel volume of 2 gallons, this aircraft can cruise at 55Mph for up to 8 hours, giving it a range of nearly 450 miles.

Payload

This aircraft allows us to accommodate an extremely large and more sophisticated payload. The APV-3 has no problem carrying 30-35 lbs. With an internal volume of 42450 cc, there is no problem fitting any payload in future. Fuel volume can also be exchanged for additional payload capacity.

Attached figures have more information about aircraft specifications and internal layouts.

Autopilot

Introduction

The aircraft must fulfill a number of mission-critical requirements. It must be able to navigate through waypoints, including those sent while in flight. The autopilot must be able to receive and execute commands specific to aircraft systems such as altitude, orientation, and velocity. Finally, the autopilot must have the ability to interface with custom payload packages such as a camera and on-board computer, allowing for the identification and location of targets.

The Cloud Cap autopilot system (Piccolo 150) was chosen because it is a well tested and extremely robust system that met all of the mission criteria. It effectively flies between waypoints, can easily fly to new waypoints transmitted to the aircraft while in flight, and has the ability to interface with custom payload packages. It is also a highly user-configurable and adaptable autopilot system, thereby allowing many modifications as needed. See figure 3 and 5 for a detailed overview of the autopilot system.

Human Interface

The means of communicating with the avionics while under autonomous control is through the use of Cloud Cap's Operator Interface program (OI 1.3.1). The interface tracks the position of the aircraft on a map, transmits updated flight commands, and streams telemetry data in real time.

A Futaba transmitter can give the pilot manual control of the aircraft during takeoff and landing phases, as well as in the event of an emergency. The operator interface allows control of the aircraft to be switched to autonomous or manual mode by the flick of a switch (located on the Futaba transmitter). When manual control is activated, the aircraft can be flown like a typical RC aircraft.

Navigation

Visualization of the aircraft is accomplished through the use of a geo-referenced map file, which calculates the GPS coordinates of each pixel of map based on the given coordinates of a few sample points. The ease of creating geo-referenced maps allows for the operation of the aircraft from multiple locations with minimal delay.

Waypoints for the aircraft can be defined in three ways: clicking the map where new waypoints are designated, manually entering coordinates into the operator interface, or by opening a previously-generated text file. This allows for a balance between precision and speed. When extremely accurate navigation is required, coordinates can be measured carefully and entered by hand. In situations where fast response is needed, a few simple clicks on the map can change the course of the aircraft. See figure 2 for a simplified flight plan schematic.

An important feature of the Piccolo system is the ability to dynamically change predefined waypoints, create new flight plans while in flight, and circle waypoints if desired. This gives the operator the flexibility to change the mission when new information becomes available as well as quickly remove the aircraft from dangerous situations where the aircraft is out of view (thus manual control is impossible).

Hardware

Below is a list of the hardware components that are directly related to the function and purpose of the autopilot:

- Ground Station (see figure 7):
    - Prolific Technology PL-2303 Serial to USB Connector
    - Laptop computer to run the Operator Interface
    - Futaba transmitter
    - Ground station from Cloud Cap
    - Ground-station antenna, power supply, GPS receiver, and cord for pilot console
- Avionics (see figure 8):
    - Piccolo 150
    - 10 Hi-tec servos
    - 1/4 wave antenna for avionics-to-ground station communication, GPS receiver
    - Pitot tube and static tube
    - Battery pack for autopilot (providing 3.6 Watts at 12V), and a separate battery pack for the servos.

The autopilot uses GPS, a 3-axis gyroscope, and accelerometer for navigation. Any gyro drift is compensated by the use of the GPS signal as a reference point for positioning.

Surface Control

Because the linkages between the servos and control surfaces create a non-linear means of control, each surface (ailerons, elevator, flaps, etc.) were individually calibrated through the Operator Interface. The calibration requires that each control surface angle be measured and recorded along with the pulse width sent to the servo. Ten measurements are performed for each control surface and then sent, via a UHF link, to the avionics.

Telemetry

Telemetry data is transmitted between the autopilot and the Operator Interface through a 900MHZ radio with a 40Kbps throughput; allowing for real-time data streaming. All telemetry data is logged by packet and stored in dated text files for future analysis.

Safety

Safety in the Piccolo system is achieved through a multi-layered process, with decisions made based on the type of problem and the possible resolution. See figure 6 for detailed procedures in the event of equipment failures.

In the event of a communications failure between the aircraft and the ground station, the aircraft will operate on its original flight plan until the interface can be reestablished. Because the manual controller works directly through the ground station, the pilot in control maintains the ability to take control of the aircraft in the event of an emergency.

If a GPS failure occurs where radio communication exists, the pilot in command will be notified using an audible warning, allowing him to take control of the aircraft if it is within visual range. If communications do not exist when GPS failure occurs, the aircraft will loiter for a predetermined amount of time before terminating the flight; normal operation will resume if the GPS connection is reestablished before the set time.

If aerodynamic termination is asserted, the pilot will enable a secondary kill switch which is controlled through a separate receiver. See figure 9 for a picture of the kill switch in operation. At this point commands will have already been asserted by the autopilot so that the following control throws are executed:

-Full up elevator
-Full right rudder
-Full right aileron
-Full flaps down

Payload

On-Board Computer

The aircraft carries an Advantech PCM-9380 single board computer. This fully functional onboard computer has a 1.8GHz Pentium M processor with 1GB RAM, 80GB 2.5" hard drive, and a 4GB CompactFlash solid state drive. The presence of the computer allows for onboard real time processing of imagery data as it is captured and also allows data to be streamed to the ground station via Ethernet. Furthermore, the computer gives the capability to record all video and still imagery with no air-to-ground transmission noise.

Imagery System

UCSD intends to fly a dual pass route to achieve aerial imagery. The goal is to autonomously identify the target, validate the target with human affirmation, and retrieve higher quality imagery used for target classification. Throughout the entire flight, a video recording program saves the footage onto the primary laptop hard drive. The video will contain the output from the Sony video camera. This video will be used in future endeavors to improve the quality of the target segmentation.

The preliminary pass through the field is a higher altitude surveillance route used to determine target locations. The system will continually attempt to identify targets based on color whose process will be described in a later section. When the onboard computer identifies a possible target, the frame used to identify the target will be saved to the hard drive and the compact flash card. Additionally, the program will store the telemetry data of the plane at the moment the picture was taken. This metadata will be used to improve the accuracy of target location identification. Upon completion of the primary sweep of the area of interest, the plane is commanded to loiter in a close proximity to the base station to ensure transfer of target images. The base station operators then perform a quick check analysis on the images to determine if a target is indeed found where the system says it is found. The images which are verified by the operators are then processed to determine approximate GPS location. The same target may be found in multiple images. We utilize this occurrence by performing a k-means like grouping algorithm on the points.

The secondary pass involves mapping out a course at lower altitude which enables higher quality photos of the images to be taken. Similar target-background segmentation will occur at this step as in the first pass. The still images will be saved to the compact flash card as they are more immune to sudden jarring. As a precautionary measure, the hard drive will be powered off during landing. The still images will be imprinted with the recorded GPS location of the target as well as a time stamp of when the target was acquired. Additionally the images will be classified with a neural network shape recognition system whose training set includes all alphanumerics as well as a basic shape set included from the Wingdings font.

The acquired targets will be downloaded to the base station and a report on each target will state the location and top 5 classifications of the target.

Target Detection

The targets will be segmented from the field primarily using color recognition. The system initiates a set of background colors by learning which colors are natural to the field. A number of aerial photographs are taken with no targets in the field of view. A program then learns those colors as well as colors similar to them. The CIELAB colorspace is the primary colorspace used to discern colors. All colors which are not considered background colors will be classified as possible target colors. Blobs of possible target color pixels are further discriminated using area requirements which are a function of the attitude of the plane. In this fashion multiple targets may be identified in the same picture. The GPS coordinates will be calculated and saved as metadata to the png image files.

Shape Recognition

Using still images acquired from the second overhead pass, our software performs shape recognition using a neural network. Targets are first cropped and rotated such that they are orthogonal to the X-Y plane. The rotation angle is also factored into the calculation of the target orientation. The targets are then passed through a neural network classifier, which outputs a single value for the alphanumeric or shape of the target in question, as well as a percentage for classification certainty. Because the natures of the targets are not revealed prior to competition, the computer is trained on a large dataset, encompassing many different fonts, shapes, as well as permutations of this training data.

Target Location

The GPS location of a target is determined by the onboard computer. The computer interfaces via RS232 serial connection to the autopilot unit to obtain telemetry measurements (GPS position, bearing, altitude). Using these measurements, the computer is able to calculate the GPS position of the targets recorded by the cameras. To do this, we use a clustering method similar to K-means clustering which allows the software to continuously recalculate the position of targets as new imagery of the targets is obtained while also eliminating false detections.

Base Station

The base station allows the payload operator to view a video stream of the imagery captured by the video camera onboard. This is to ensure that the computer and all other payload components are operating correctly. Furthermore, the operator can send commands to the onboard computer, download high resolution still imagery while the aircraft is loitering, reset the computer, or shut it down via the wireless Ethernet link.

Classifications of targets and calculations of target locations made by the onboard software are verified by the ground operator at the base station. This is to ensure that the system did not falsely classify a target or miss a target.

Wi-Fi

There were assortments of off the shelf products that fit the minimum criteria of the project. The unfortunate part of vouching for an off the shelf product from companies such as Microhard and

Maxstream were that they were crippled in terms of total throughput. For scalability the team decided to go with a modified WiFi system. After much research, it was concluded that with a little tuning, the scalability and the flexibility of system would be the best choice. The modified WiFi system consisted of a hacked Linksys WRT54GS Router (ground station) and a Pasadena Wireless USB NUB-362(EXT) Client (air station). The Linksys router was modified with 3rd party firmware (DDWRT) and amplified with a custom made 1Watt Amp. Attached to its' TNC antenna expansion port is a directional Horn antenna that is manually aimed by an operator.

Image Acquisition

System Goals

A high quality reliable imaging system is a vital part of the total payload package. The onboard optics provides the only visible link between the aircraft and its operators. The purpose of this system is to maintain live streaming video from the target field to the ground station, and to have the ability to take high quality still images of targets when recognized.

System Components & Highlights

- Sony FCB-780BP block video camera
  - 0.800 Mega pixel resolution
  - 300x total zoom (25x optical, 12x digital)
  - Image stabilizer
  - Various automatic functions
    - Exposure, Focus, White balance
  - Six programmable memory locations to specify camera settings
  - Low power consumption (1.5W motors inactive, 2.7W motors active)

- KWORLD video capture device
  - Provides analog to digital video conversion
  - High speed USB 2.0 connectivity

- PVR Plus video capture software
  - Watch and record live video
  - Snapshot sampling
  - Easy to operate

The choice of using a single video camera, camera selection was critical. With the large available zoom of the block camera, a separate still camera is not a necessary component of the payload package. The decision to remove a possible still camera decreases the overall mass of the payload and increases useable volume for other components. The built in image stabilization of the camera is another key feature in ensuring high quality video to promote the ease and accuracy of target recognition by reducing effects from vehicle motion and vibration. The low power consumption of the camera again saves weight and room in the payload tray by allowing for the construction of smaller batteries. This is an important point because the onboard batteries are a major contributor to the overall weight and size of the system.

This combination of products provides a simple easy to use solution. The camera has been altered to connect to video equipment via standard RCA or S-Video connector. Once the signal has been sent from the transmitter to the receiver on the ground it is converted to a digital signal by the KWORLD converted which can be connected to any computer with an available USB port. Next the PVR software allows for recording of the video with one click of the mouse button. Still shots can be captured out of the video by clicking on the snapshot button on the user interface. These video and still images are saved by the software with default date and time names, or they can be saved with specified names to specified file locations. Once the files are saved they are easily accessible for review to find possible missed targets, and for target confirmation.

Air vehicle specifications	RnR RPV-3
Length, Wingspan	2m, 3.75m
Weight	13.6 kg
Payload capacity (weight)	9kg
Payload capacity (volume)	42,475 cc
Engine Type and Hp	86 cc Fugi 2c gasoline, 7.5 Hp
Cruise airspeed	43.5 knots
Vso	24 knots
Endurance (hours)	8 hours
Range (Miles)	440 miles
Service Ceiling	9000 feet ASL
Takeoff distance	40 meters
Landing distance	80 meters
Maximum cross wind velocity for safe takeoff and landing	15 knots

Figure 1: Basic-aircraft specifications

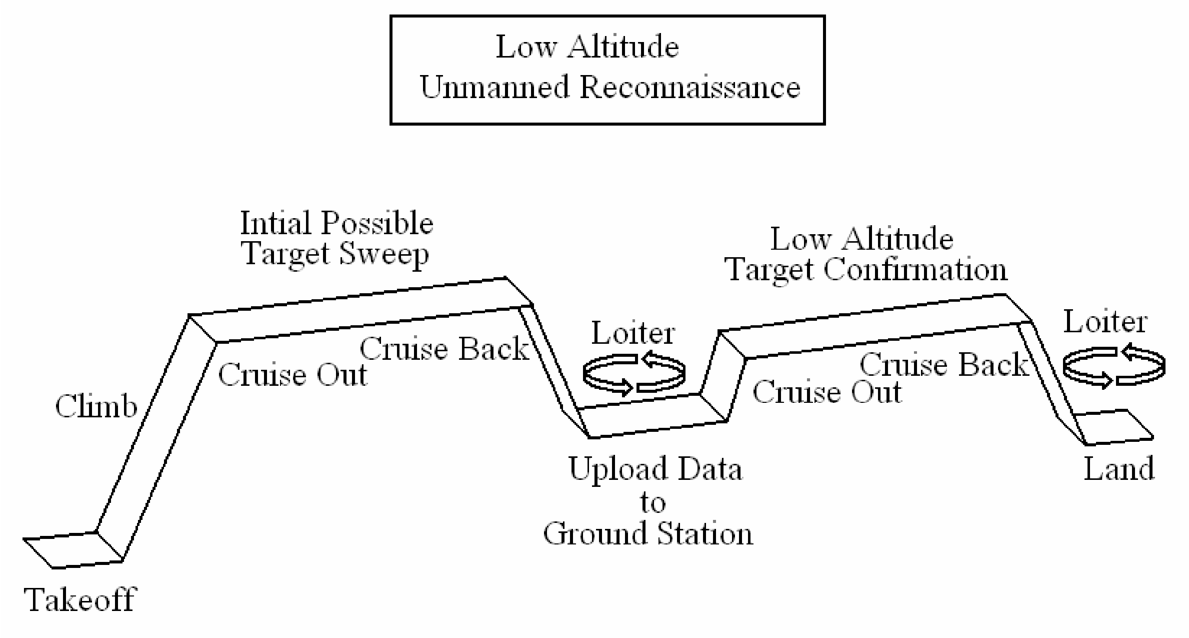

Figure 2: Simplified-flight path

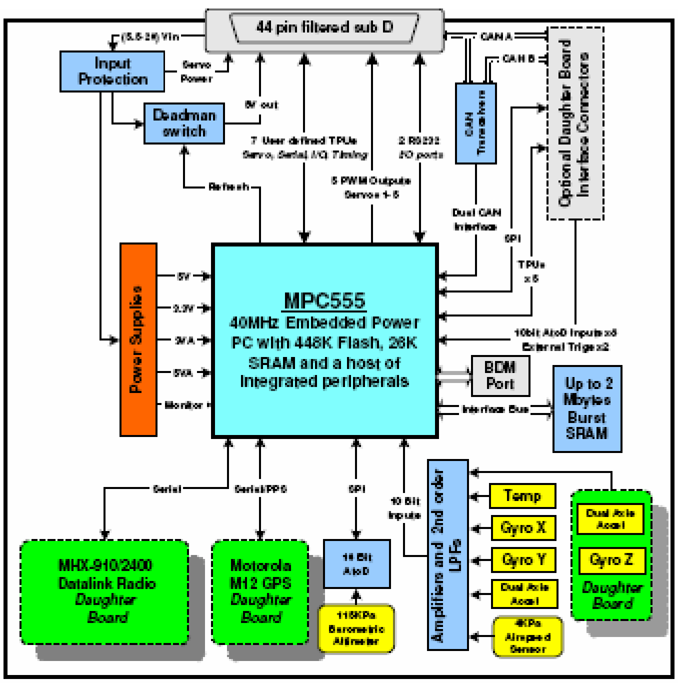

Figure 3: Piccolo schematic

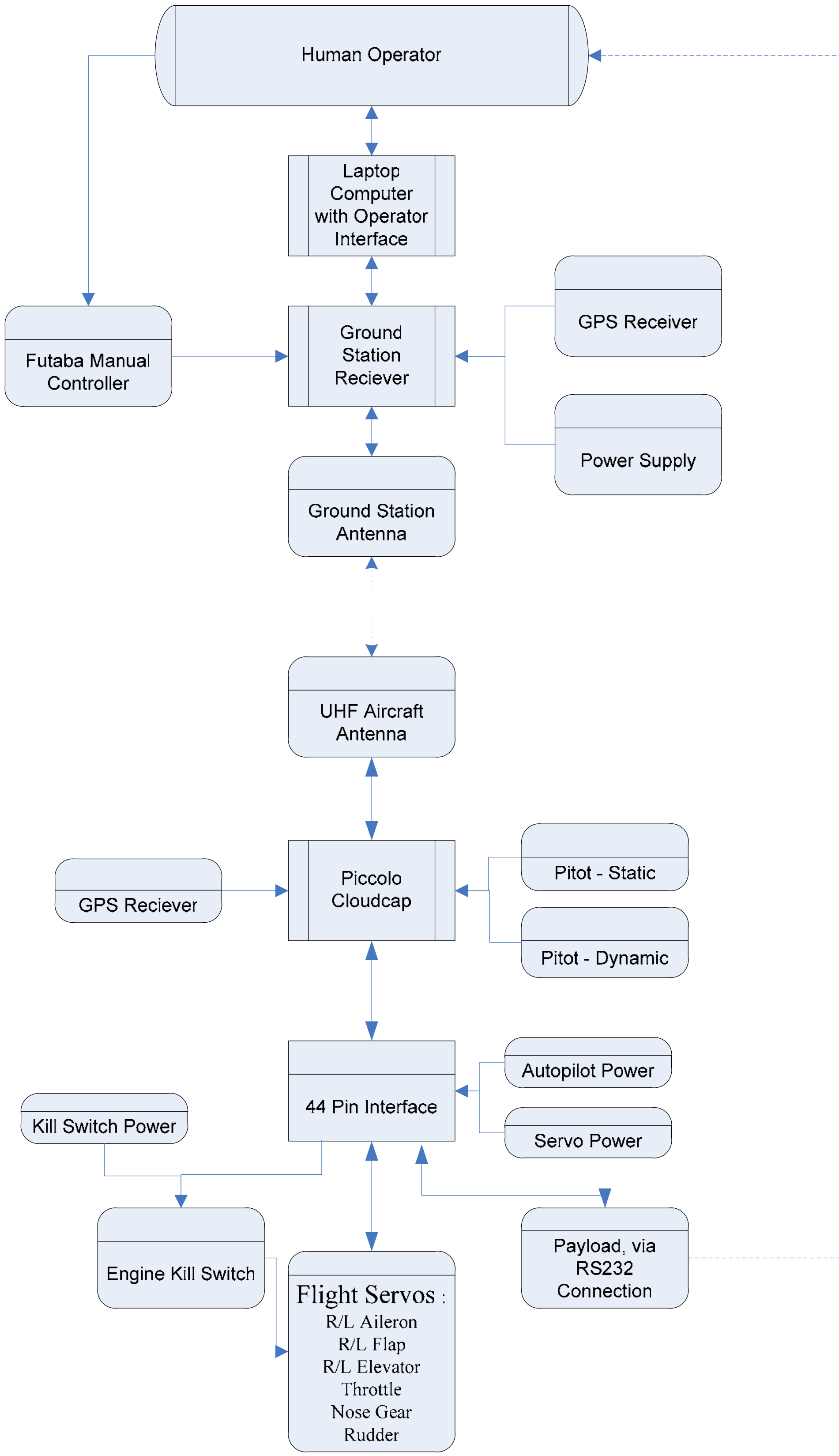

Figure 4: Autopilot interface

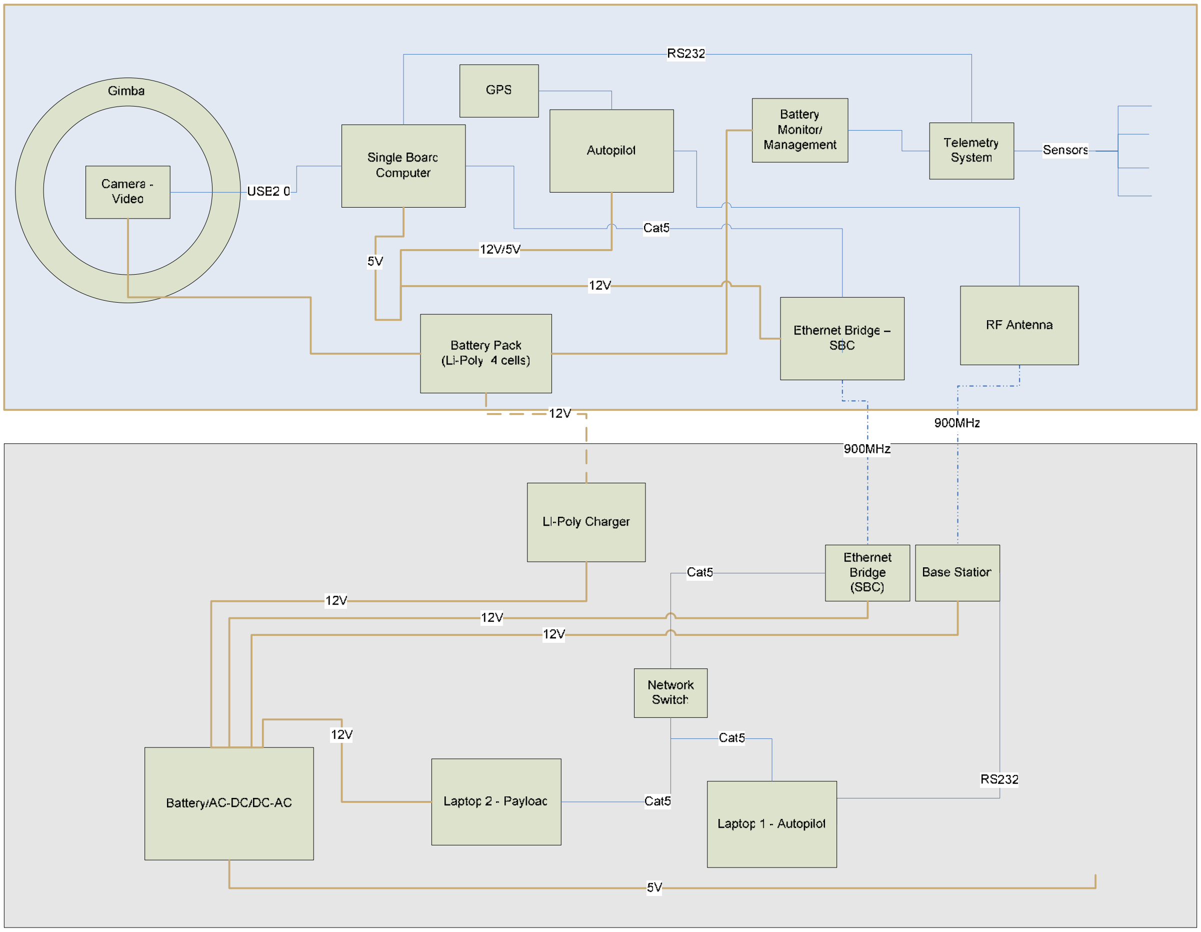

Figure 5: Ground station and fuselage electronics-layout

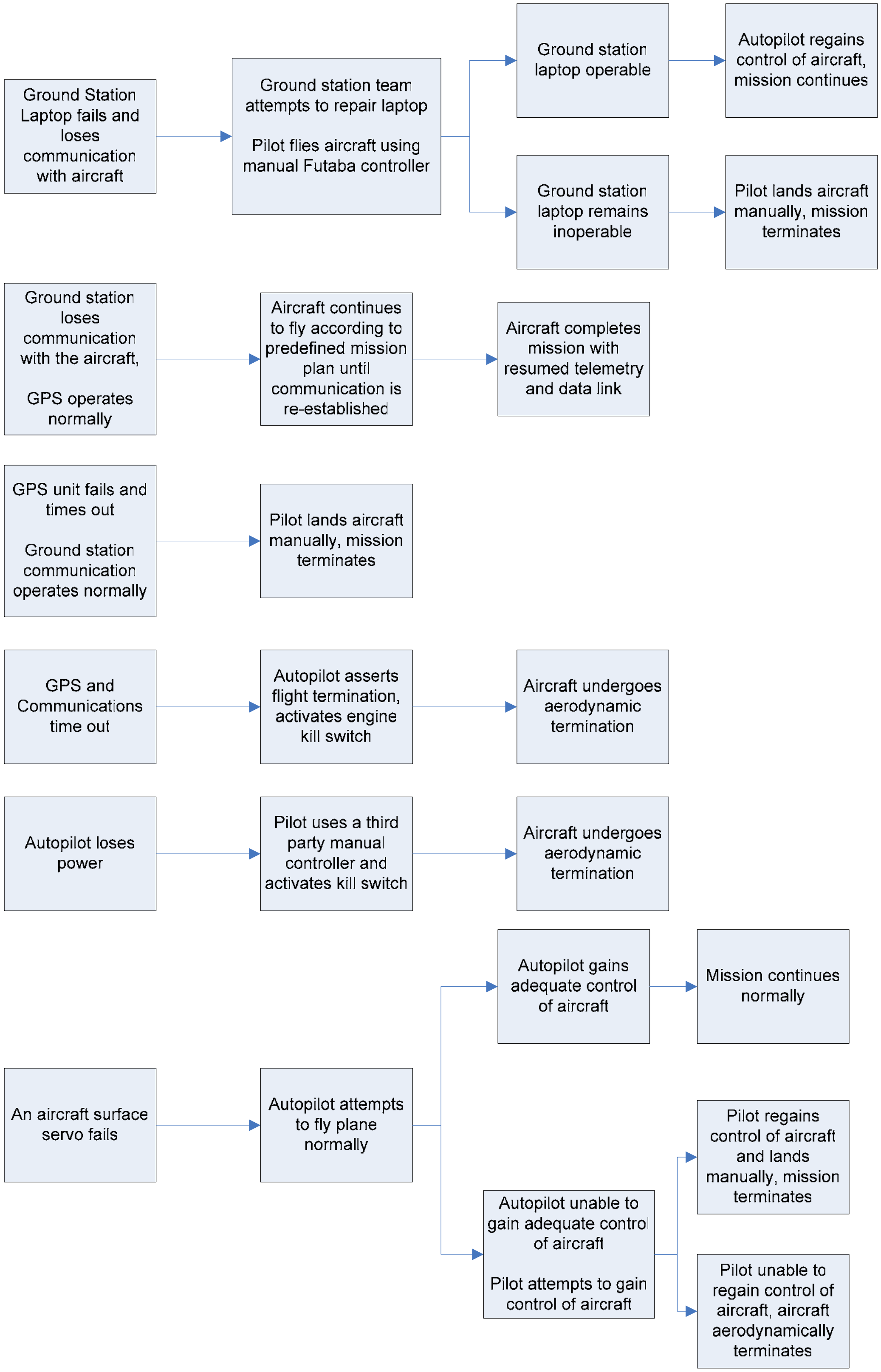

Figure 6: Safety procedure flow

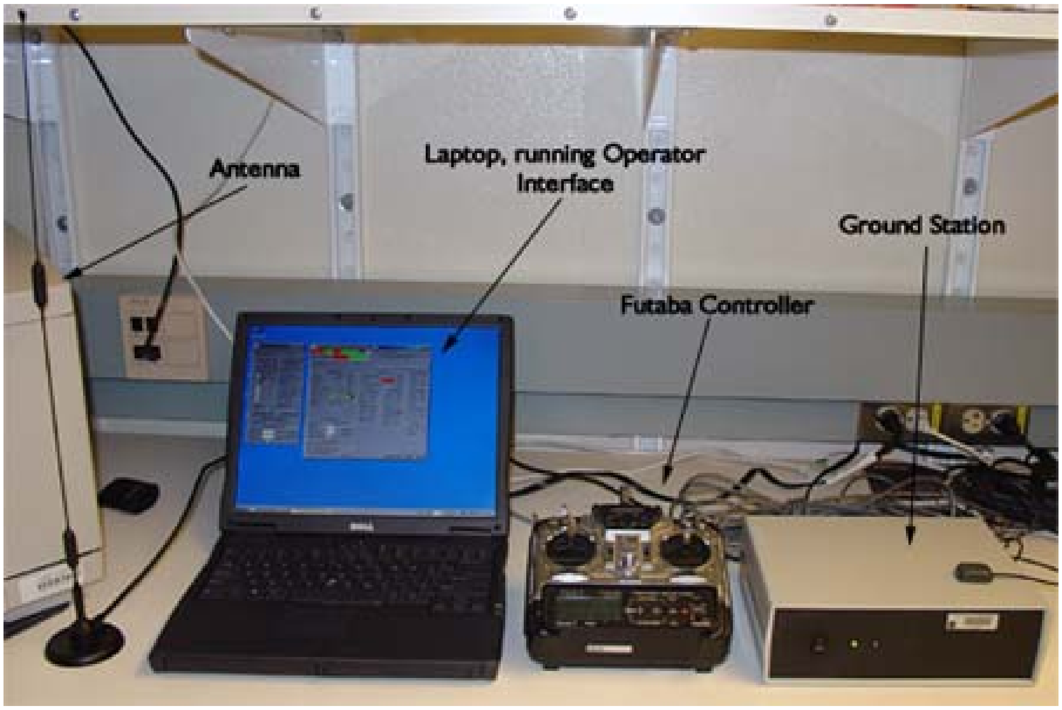

Figure 7: An overview of our ground station hardware setup

Figure 8: An overview of the avionics, showing overall installation, inputs, and outputs

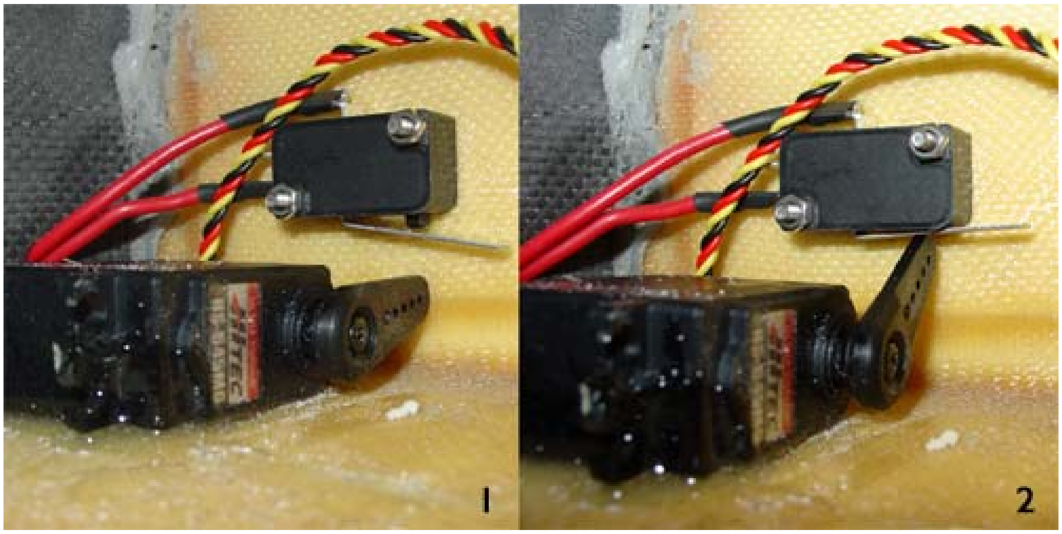

Figure 9: 1- Engine kill switch disabled, engine operating normally
2- Engine kill switch enabled, engine halted