AUVSI Student UAS Competition

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Great Mills High School Engineering Club Team

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I. Abstract

The Great Mills High School Team's Unmanned Aerial System (UAS) is entering into the 2012 AUVSI Student UAS Competition. The UAS is composed of two technical subsystems, one Unmanned Aerial Vehicle (UAV) that autonomously takes flight and the Ground Control Station (GCS) which interacts with the UAV's internal MicroPilot autopilot and directs flight parameters.

II. Introduction

Four years ago, the Great Mills Unmanned Aerial System (UAS) team acquired resources, comprising a plane and an integrated MicroPilot autopilot avionics package that enabled them to compete at Patuxent River Naval Air Base in the 2009 AUVSI competition. This year's project is a continuation of the pioneer project the Great Mills UAS team set in motion in the previous years. The team purchased and built a kit plane and also bought a back-up aircraft of the same model.

III. Mission

The general mission scenario dictates that a team of Navy Seals has been tasked to rescue family members of international diplomats held hostage in a designated airspace (Webster Field). This area contains targets that must be recognized. Point reconnaissance may also be conducted.

The mission is sectioned into four phases:

(1)Takeoff
(2) Waypoint Navigation
(3) Target Recognition
(4) Landing

(1) The first phase consists of a difference between autonomous and manual takeoff, with additional points given to the former. UAVs can take to the air in either manner while still being able to complete the second phase.

(2) The second phase is split into two tasks. The first task requires pre-planned autonomous navigation to GPS coordinates announced the day of the competition, described in latitude, longitude, and altitude components. The second task consists of adjusting waypoint navigation in order to avoid in-flight hazards.

(3) Target recognition involves the correct identification and location of designated targets ranging in colors (Red, Orange, Yellow, Green, Blue, Black, & White). GPS location, heading, target color, target shape, alphanumeric, and alphanumeric color are all aspects of the target recognition task.

(4) Autonomous landing will also score bonus points, but is not a mandatory function.

IV. Mechanical Design

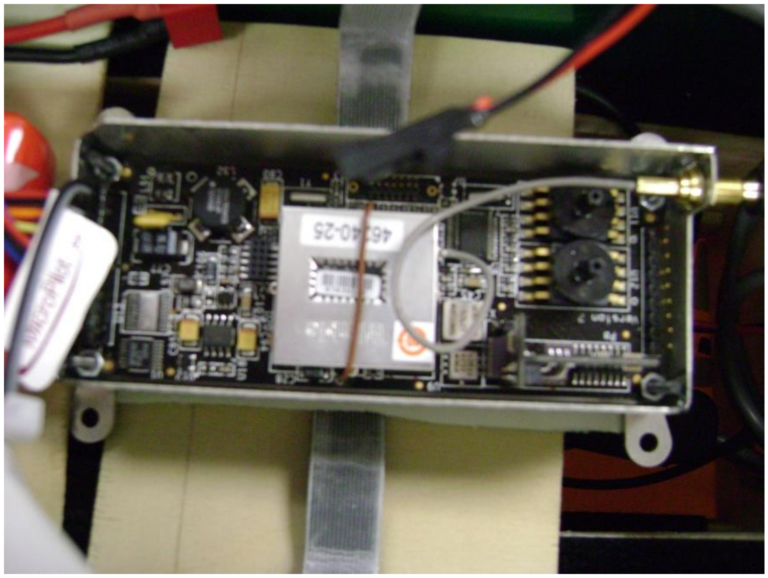
The airframe being used is a Senior Telemaster that has been modified to hold an autopilot and camera in order to complete the assigned tasks. The plane has a wingspan of 95”, length of 60” and an empty weight of 12.9 pounds. It is propelled by a 1.20 Rimfire electric motor which is powered by a 6S 5000mAh battery pack. This year the team switched to an electric motor from a gas motor to cut down on weight and reduce vibration for the camera system, as well as reducing ground maintenance by not having to use fuel. The propeller is a 16x8 (diameter by pitch) and is manufactured by Master Airscrew.

The primary airframe being used was built two years ago from a kit by the student team members with supervision by the mentors. It was first constructed to be capable of flight, and after we had proof of capabilities, we created a series of shelves to hold everything needed for flight, autonomy, and camera payload. The airfoil can be repaired with balsa in a variety of sizes and exterior components are easily maintained with covering film.

On the front of the plane is GPS antenna for the Range Video system, above the motor housing. The plane’s flight battery is located in the compartment directly behind the motor housing, in front of the old firewall. The autopilot, along with its transmitter and battery pack, is located in the section under the wing. In the next compartment are the main camera and the Range Video On-Screen Display as well as the back-up camera. Everything is arranged on a series of shelves attached to the sides of the fuselage by Velcro for easy access to all parts and security in the plane while in flight and transit.

The autopilot GPS antenna is then located on the exterior of the plane’s top side directly behind the motor on top of the panel covering the flight battery pack. The Radio Control (R/C) antennae is threaded through and attached to the top of the rear of the aircraft. Aft of the camera equipment, the fuselage is scarcely populated and only has the two servos controlling the elevator and rudder control surfaces. This arrangement helps to maintain a stable center of gravity and properly distributes the flying weight.

V. Electrical Design/Autopilot



The avionics installed in the fuselage include a MicroPilot 1028_g autopilot, manufactured and sold by MicroPilot. The autopilot system is comprised of a microprocessor, GPS, 3-axis gyro, and air data sensors. The autopilot is designed to allow flight control in either manual mode (Pilot in Control (PiC)) or autonomous mode (Computer in Control (CiC)). PiC mode bypasses all autopilot functions and allows direct R/C control of the servos via a Mux board acting as a Safety (Fail-safe) Switch if the autopilot fails. In PiC mode, the Senior Telemaster must be flown following Visual Flight Regulations (VFR). In CiC mode, the autopilot provides control. The autopilot has 12 feedback control loops: ailerons from roll, elevator from pitch, rudder from Y accelerometer, rudder from heading, throttle from speed, throttle from altitude, pitch from altitude, pitch from AGL (enabled during landing and controls the flare), pitch from airspeed, roll from heading, heading from cross-track error, pitch from descent, and roll from radius. Although in the beginning of the year, we planned on full autonomy for the waypoint navigation portion of the mission, we decided to resort to R/C flight because of unforeseen obstacles and limitations of the acquired autopilot system. Recently, the problems have included difficulty in servo calibration, radio modem communication, and a malfunctioning home base computer. These issues caused delay in autonomy.

1. MP 1028_g Core

The MP 1028_g Core contains the microprocessor of the autopilot and acts as the control mastermind of the UAV. It directs information, processes actions, and records results, sending them down to the GCS through the data link. In addition, the core houses gyros, accelerometers, air pressure monitors, and other vital air data sensors.

2. Servo Expansion Board

The Servo Board connects the autopilot to the avionics control servos including the rudder, throttle, elevators, and ailerons. These are input into their respective ‘S’ slots via the standard three pin connectors. Through the expanse of this year’s competition, we have revised our servo board connections and wiring. We have altered some of the wiring connections with Dean’s connectors to prevent faulty wiring. In the original format, our organization of the internal network involved three batteries.

There were inter-connecting circuits within the circuits leading to power-loops causing interference between the power sources and loads. To mitigate this issue, we removed the positive and negative wires from the fail-safe switch and from the R/C receiver, leaving only the control lines. Only the direct connections to the actual servos remain intact with pos/neg wiring because they are individually isolated. We removed the receiver battery and decided to draw power through the fail safe switch’s supplied power via the “gear” switch servo line; this is the only line that is connecting the R/C receiver that closes the circuit with positive and negative wires so it must be connected because the R/C receiver must have power at all times to facilitate switching between PiC and CiC modes. This isolation was done because the R/C receiver’s channels are all grounded unto themselves, and the fail-safe switch selections are also grounded unto themselves, but we needed to isolate those two ground planes to avoid ground looping within the entire system.

3. <u>GPS Antenna</u>

The GPS Antenna connects the autopilot directly to triangulate current position, velocity, and altitude.

4. <u>Compass</u>

The Compass gives vital information such as heading, wind speed, and wind direction, allowing for a dead-reckoning capability in the event of a data-link/satellite-link catastrophic failure.

5. <u>R/C Receiver</u>

The R/C Receiver is the standard PiC remote-control connection link that came standard with the Senior Telemaster. The receiver is connected to the failsafe in order to allow an in-flight PiC/CiC switch in the event of that the autopilot becomes incapable of maintaining control.

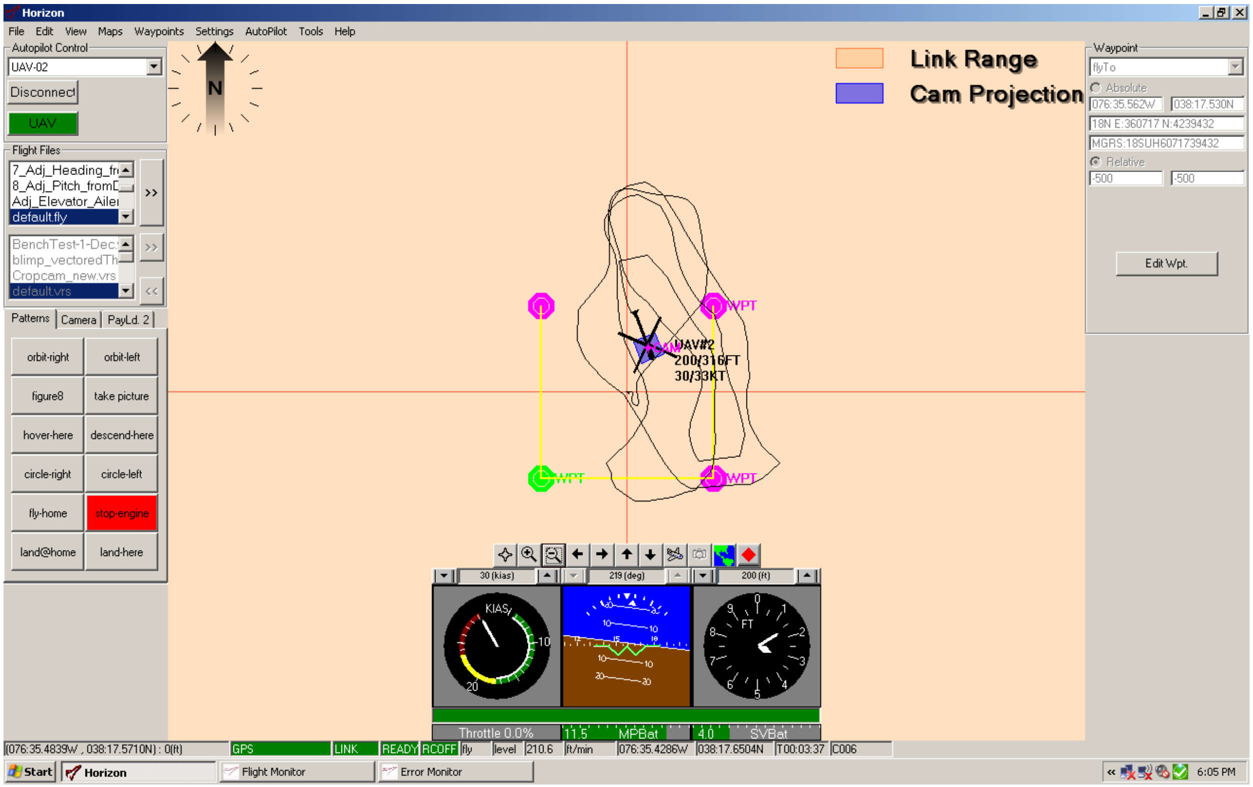
6. <u>Radio Modem</u>

The radio modem is the medium through which connection is achieved between the GCS and the autopilot. Our team is currently using an XTend-PKG 900 MHz USB Radio Frequency Modem to communicate between the GCS and the autopilot.

7. <u>Fail-Safe</u>

The fail-safe for our system is built into the R/C controller. The safety pilot will use the dead-man stick to switch between PiC and CiC. When the autopilot is in control an R/C link must still be established. If the R/C link is lost while in CiC mode, the plane will terminate itself. If the autopilot fails, the safety pilot will take over in PiC mode. In the event of both autopilot and R/C link failing, the plane will receive a signal to terminate itself. Recently, our fail-safe switch malfunctioned, causing us to forgo autonomy.

VI. Software



Horizon 3.4 Interface:

Horizon is the sister software of the 1028g MicroPilot autopilot. The program is used on a Dell Precision-670 computer.   The Horizon software provides situational awareness of the UAV's environment, including altitude, airspeed, wind speed, attitude, heading, and GPS location. The GCS also monitors autopilot, C2 link, and power.

From the GCS, operators are able to communicate with the autopilot of the UAV so that it will autonomously take off, land, and follow previously determined flight patterns. However, the autonomous take-off and landing aspect of the software has not been explored or set up because the team does not plan to autonomously take off or land during the competition. Flight patterns are recorded by entering a series of waypoints into the GCS, allowing for the control of altitude and GPS location of the vehicle. Flights can be simulated well before actual flight to show how the UAV would respond in normal flight conditions to the flight pattern.

Prior to take-off, internal pilots map and plan out a waypoint file that depicts a GPS point-to-point itinerary for the UAV as it is airborne. Generally, these waypoint flight paths are generated by manually adding waypoints and dragging them to their desired locations. Waypoint maps can be created by entering in GPS coordinates as well, allowing for accuracy, quick and easy integration, understanding, and versatility. During the AUVSI competition, the internal pilots will attempt to create a waypoint map that will produce a video clip which will cover a maximum amount of the operational area using search patterns such as the teardrop pattern, the square spiral pattern, and the ladder pattern.

One of several key concerns of internal pilots is the physical orientation of the plane. The two cameras are located on separate, remote-controlled, rotating gimbals on the underbelly of the aircraft. The larger video camera faces forward and the smaller camera faces backward, but both can be rotated on their respective gimbals to create a larger range of view. The gimbals allow the cameras to stay trained on separate targets during flight.

Another concern is the spacing between parallel flight paths, as well as the clearance of the flight path with the defined safe operational boundaries. Internal pilots use the ‘ruler tool’ to measure consistent distance between points along the flight path.

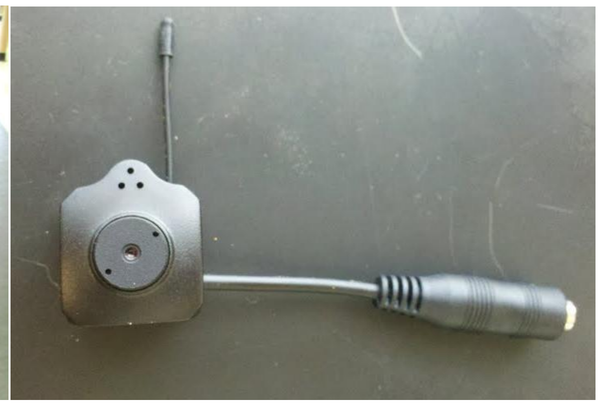
Internal pilots also have to keep in mind the available flight time and fuel as they construct their waypoint map. Some maps can be comprehensive, but far too lengthy, while other maps may be less inclusive, but fall within the time frame. Internal pilots must find that delicate balance in order to create the best-fit scenario.

The GCS screen can show a map of the flight area when it is downloaded to the GCS. The available map is extremely helpful in aiding the operator in better understanding the environment of the UAV, in a simulation or during flight, so that operators can make flight adjustments as necessary. Simulated flight aids are helpful in predicting any possible problems such as a breach of boundary or not covering target flight path.

Adjustments during flight can be made by GCS operators to correct any previously made errors or unexpected occurrences. The operators make use of aircraft readings such as altitude, attitude, airspeed, and heading to recognize when flight adjustments are necessary. Then, the GCS operators use screen features to make adjustments.

They make changes to altitude and airspeed through selecting up or down arrows on the corresponding screen features. The operators also make changes to GPS location through entering GPS coordinates of waypoints on the map, thus changing the flight pattern.

VII. Payload



1. <u>Visual Systems</u>

The visual system is comprised of two separate cameras, each equipped with their own respective gimbals and transmission systems. We have chosen to integrate an additional camera, as well as gimbals for each camera, in order to facilitate the ability to search areas of the field that are not directly beneath the aircraft during flight (versus our previous configuration in which we had one stationary camera).

One of the cameras (located above-right) is a spotter camera, and will be searching for targets to identify on the next search pattern. This will allow us to customize the next flight path so the other camera system (located above-left) will be able to identify more targets on the next pass. Having two separate visual systems eliminates the need to aimlessly search for our next destination, making efficient use of time.

2. <u>Cameras</u>

Our identification camera is the JVC Everio video camera. This camera is able to record in flight should the wireless feed fail. It can also zoom up to 40 times (optically) without hindering the video resolution (840x624), which will allow us to identify targets more accurately.

Our spotter camera is a miniature lightweight device that has a transmitter integrated into its body. This camera has a resolution suitable for viewing the field in order to spot targets for flight path alteration. This camera is powered by a separate Lithium polymer battery rated to provide more amp-hours than are required for the mission.

3. Video Link

The wireless transmitter for the identification camera is a 2.4 GHz RangeVideo transceiver, accompanied with the RangeVideo RVOSD (RangeVideo On Screen Display). The RVOSD provides useful information on screen such as altitude, GPS coordinates, wind speed, and temperature over the original video feed. At ground control, there is a paired 2.4 GHz receiver that will collect the video being transmitted by the plane, and the feed will be routed simultaneously into a computer via a PCMCIA video capture card as well as a television at ground station. This setup will allow our team to effectively view live footage as well as rewind to further analyze the footage to locate targets.

The spotter camera has an independent 2.4GHz transmitter that is paired with a dedicated receiver. This feed will be routed to a second computer at ground station via a capture card, and will be operated by another video analyst.

4. Wireless Repeater

The team will be using a Linksys WRT54GL with DD-WRT third party firmware installed, in order to connect and extract information from the Unattended Ground Sensor. The router is configured to act as an IEEE 802.11g repeater. This which will bridge a connection to ground control so it can be used to transmit data from the microcontroller. The Wi-Fi signal from the ground station is received and repeated via omni-directional high gain antennas to communicate with the router mid-flight. The DD-WRT firmware gives us access to almost all of the hardware features of the router, which is currently used to increase the stock power of the antennas and increase the clock speed of the router's SOC (System On a Chip).

5. Microcontroller

An Arduino Uno R3 with an Ethernet shield is used to monitor the angles of the gimbal on the identification camera. The Arduino is connected directly to the servo motor control lines and monitors the PWM (Pulse Width Modulation) signal used to drive the motors. The width of each pulse directly controls the angle of the servo, which allows us to calculate locations of targets on the ground. The Ethernet shield is connected to the wireless router via an Ethernet cable and it streams servo angles over the router to the ground station. The Arduino can also be used to stream data from other sources through the router via Ethernet shield.

VIII. Strategy Rationale

In the first phase teams are to successfully take off, which can be done autonomously for points or can be done manually. With our teams experience with autonomous flight we have chosen to instead take off manually and once in the air switch over to the autopilot.

The first task of the second phase should be relatively simple to complete on the assumption that the autopilot is correctly calibrated, as the Horizon software inherently gives the ability to design waypoint maps and adjust the course in-flight.

The second task of the second phase has been eliminated from our task list due to our amateur skill level with the autopilot. Instead of deviating from the given coordinates to avoid the in-flight hazard, we have decided to fly the given coordinates as is.

The third task is to locate targets on ground and give their specific location. This task will be executed using our identification camera. We will use the combination of the microcontroller and the gimbal to triangulate the position of the targets on the ground. If this were to fail, the camera will be pointed downward in order to fly over the targets. Our video feed will be sent to our RVOSD where we will be able to record our feed so we can review our footage and locate targets.

The third phase requires successful landing of the UAV. This will be done manually, as the take off will be.

IX. Testing and Evaluation

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1. First Flight Test: Helwig Field
   -testing basic flight performance in takeoffs, an oval flight pattern, and recovery
   -successful flight
   -improved flight checklist and procedures

2. Second Flight Test: Helwig Field
   - flight test with camera onboard recording
   -successful flight
   -propeller batteries are discovered to be too small

3. Third Flight Test: Helwig Field
   -testing wireless transmission system while in flight and retrieving feed to GCS
   -successful flight

4. Fourth Flight Test: GMHS Field
   -testing aircraft for connection with multiple gimbals and wireless camera systems
   -failed flight
   -transmissions created heavy interference

X. GMHS UAS Team

-Flight Test Coordinator (FTC)

- The FTC runs every flight, communicating between the safety pilot (SP), autopilot operator (AO), and payload operator (PO)

-Aircraft Handlers

- These are the mechanical engineers of the group. They oversee, operate, and maintain the airframe, autopilot, electronics board, servos, engine, and overall well-being of the UAS

-Autopilot Operators (AO)

- AO group operates the autopilot from the ground control station (GCS). They plan and direct waypoint navigation while observing real-time instrument feedback.

-Payload Operators (PO)

- PO group is in charge of running the RVOSD and analyzing footage from the GCS.

-Judge Coordinator (JC)

- The JC is a person available in the GCS to answer any questions judges have during flight when we are operating our systems.

XI. Acknowledgements

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