VCU School of Engineering
Virginia Commonwealth University

Autonomous Aerial Vehicle and Ground Control System

Association for Unmanned Vehicle Systems International

Student UAS Competition 2011

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1 Abstract

The following paper describes the Virginia Commonwealth University (VCU) Student Unmanned Aerial Systems (SUAS) competition systems design and development for the year of 2011. Mission requirements analysis is included as well as the design rationale and development details for all aspects of the VCU air system. The flight system is broken down into subsystems consisting of the VCU developed Flight Control System (FCS) “Skyline” and ground control station (GCS) which are used to autonomously guide the UAV through user designated way points and execute a search patterns. The payload consists of imaging and positioning devices allowing for target recognition and georeferencing. Redundant failsafe features ensure safe and reliable operation of the vehicle.

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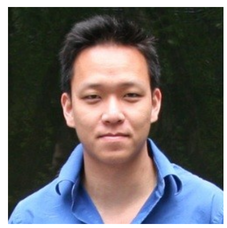
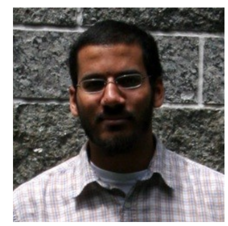
3 Team Members

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4 Mission and Requirements Analysis

In order to fulfill requirements for the SUAS competition the Unmanned Aerial System is designed to fly through designated way points while identifying targets that lay on the ground. The aircraft must also be able to give sufficient data to the ground control operators so that they may act on these target assessments in real time. Dynamic re-tasking of the flight path is also possible. The aircraft must be able to complete all its tasks before 20 minutes in which the mission window will be over. Application specific requirements will continue to be analyzed throughout the paper as they apply to each individual system.

5 Design overview

Figure 1: Images of the aircraft

5.1 Systems overview

The autonomous flight system operates by utilizing a distinct modular design for flight control, payload management, communication, command system, and data analysis. The flight control contains manual RC controls for takeoffs, landing, and emergency takeover should the autonomous system fail. The autonomous flight system takes over after the UAV has been launched and is directed by the ground station that uploads way-points that the UAV then flies to. The payload consists of a high definition camera controlled by a two axis gimbal with an independent inertial measurement unit (IMU) for control and target location. Communication with the UAV is provided over three different systems: payload control, manual RC control, and autonomous flight control module. This separation of systems helps provide redundancy improving safety and reliability. Should any one system fail, flight control is still maintained. The command system and data analysis resides at the ground station with independent interfaces for flight control and target recognition. The command system is comprised of a server/client pair allowing the flexibility for multiple UAV's to be run simultaneously as well as multiple clients controlling a single or several UAV's.

5.2 Expected Performance

5.2.1 Preflight check

During the preflight check a complete systems check is performed providing operational capability and safety check. Way-points for flight can also be uploaded at this time. Systems are powered up and the engine is fueled.

5.2.2 Launch

The engine is started and manual RC flight is used to launch the aircraft and climb to operational altitude where the autonomous flight system is then activated.

5.2.3 Flight

Way-points can be preloaded or given during flight. Existing way-points can also be modified at any time. Flight is autonomous but a pilot monitor's flight during the entire mission ensuring the correct operation of the vehicle and providing validation of safety. During flight the camera is used by ground control operators to scan for intended targets. Target recognition aids ground control users in identifying possible targets as well as identifying the location of the confirmed targets.

5.2.4 Landing

Upon mission completion the UAV returns to a designated landing spot where manual control of the system is then obtained. At this point the vehicle is landed manually and shut down.

5.2.5 Test and evaluation results

Tests indicate that the UAV performs well in maneuvering and based on current fuel consumption should be able to carry the payload at 45 knots for a duration of about an hour. The navigation system responds well and operates as expected, efficiently completing waypoints while the payload reliably gives video feedback.

6 Design Descriptions and Rational

6.1 Air vehicle

The UAV is a fixed wing plan. The vehicle has a 100" wing span with 84" body length and approximately 30 pounds providing capability for large payloads and better flight stability in non-ideal weather conditions. Propulsion is provided by a two stroke gas engine.

6.2 Ground control

The Ground Control Station or GCS is the essential link to the aircraft. While the GCS is a flexible modular system, the standard configuration is comprised of at least 2 computers and 3 monitors. The distinct modules include the GCS server, GCS control client(s), video station, image analysis, and the camera control client.

6.2.1 GCS Server

The main GCS system runs the server in which the airplane data is stored. This server also functions as the radio link to the aircraft transmitting commands to the aircraft and receiving flight data from the UAV. The server can be used to remotely update data on any number of ground control clients. This allows for a good deal of modular additions to the basic functionality of the GCS control module.

6.2.2 GCS Control Client Interfaces

The GCS Control client is the main station where commands are sent to the FCS on board the aircraft. It consists of several different control interfaces that together allow complete control of the air system.

6.2.2.1Main Display Interface

The main display contains a map which allows for adding way-point s to the flight path at any time during the mission. Featured prominently is a satellite image of the flight zone. This interface displays no-fly zones, search areas, flight path, identified targets as well as the current heading, position and actual flight path of the vehicle. All of this is modifiable using a simple point and click interface.

Figure 2: Example display interface

6.2.2.2Telemetry Panel Interface

The telemetry panel contains the following information providing feedback in either English, Metric, or nautical units where appropriate.

- Mode of vehicle operation (Manual/Autonomous)
- Vehicle Altitude(above sea level and above ground level)
- Vehicle Position(Latitude, Longitude)
- Vehicle Orientation(Pitch, Roll, Yaw)
- Vehicle Velocity Info (Air Speed, Ground Speed, Ground Track)
- Vehicle Fuel Levels and approximate flight time remaining
- Status of wireless communications link
- Diagnostic information

6.2.2.3Telemetry Gauges

Selected telemetry data is also shown in the form of graphical instrument gauges for easier reading by operators and judges. Gauge position, size and units of measure can also be adjusted by the user. The following gauges are included:

- Altimeter: Displays both current altitude and target altitude
- Speedometer: Displays both current air speed and target air speed.
- Compass: Displays vehicle's current heading and ground track.
- Attitude: Displays vehicle's current pitch and roll

6.2.3 Parameter Control Forms

In addition to the various interfaces, the control client features collapsible parameter entry forms along the right hand side of the display. This allows for quick access to flight parameters without cluttering the display area. In addition to allowing adjustments to target air speed and altitude, the flight operator can make adjustments to the aircrafts persona Identification (PID) control parameters and server trim values if necessary.

6.2.4 Target Georeferencing and Image Client System

In order to meet the goals of the SUAS 2011 mission, the imagery analysis must be able to capture and display images to the judges during the conduct of the mission or when handing in the mission report sheet. The system must identify the target parameters from various altitudes and proved actionable intelligence including imagery, location, color and other parameters to the judges. In order to best achieve these goals the target recognition system was split into two parts, the video receiving station and the image analysis client.

6.2.4.1Video receiving station

The video client provides real-time feedback of the aircrafts payload video camera. This allows for initial searching for targets as well as verification of the aircrafts performance and location. The video client is synchronized with the telemetry data as it is received. This resolves latency problems due to required buffering of the video stream for assisted target recognition and analysis. The video station includes a database of past values of certain flight parameters needed to perform georeferencing of the obtained images.

Whenever the user selects a frame in the video feed that he/she believes contains a target, the history database provides the time, position, and camera angles at the time the image was taken. This image obtained from the video feed, along with the positioning data is saved on the computer to be used by the image analysis client.

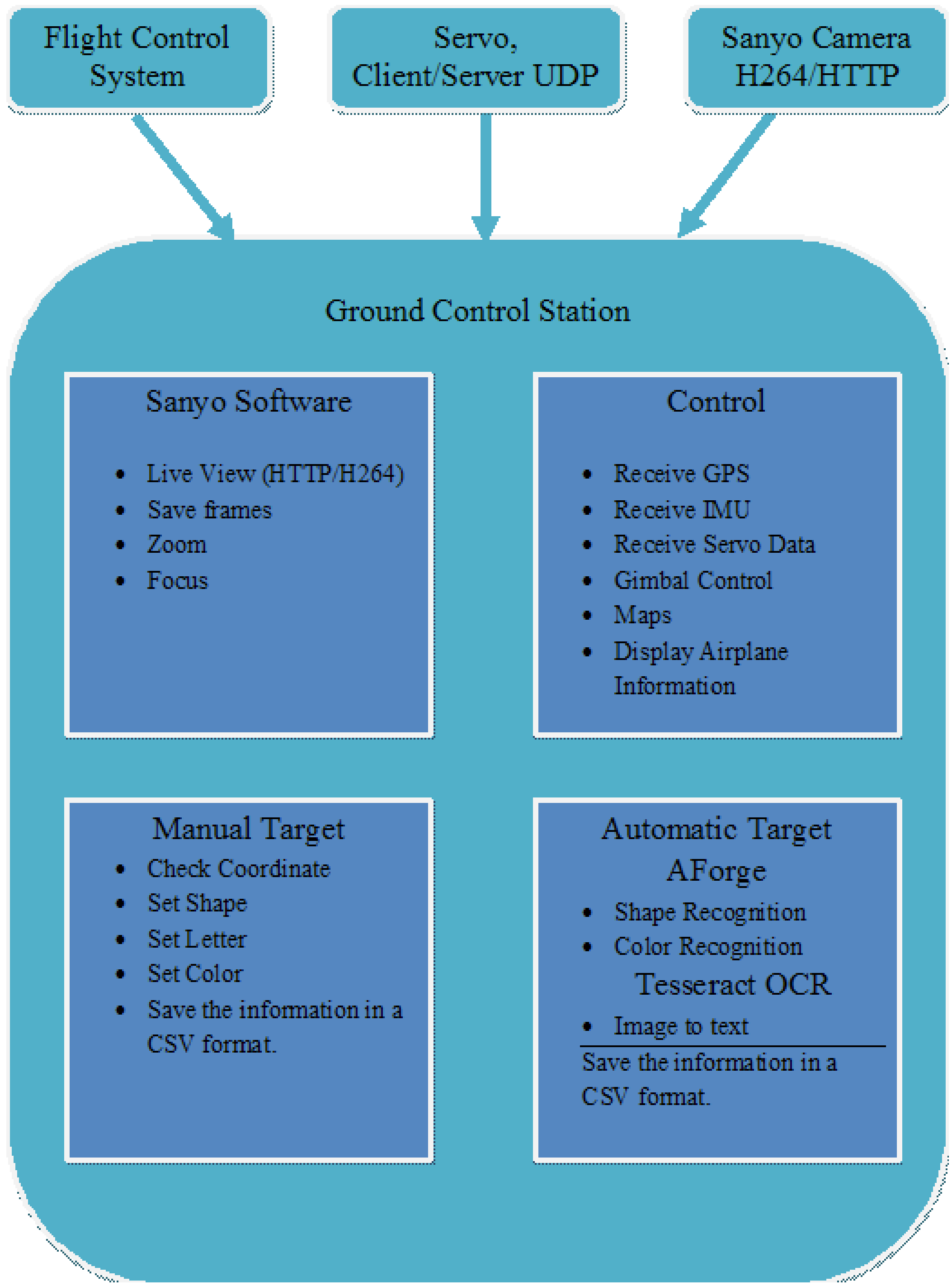
6.2.4.2Image Analysis Client
The image analysis client is run in concurrence with the video receiving station. The program allows the analysis operator to review the images captured from the high definition video camera and determine if there are targets within the image. If the suspected target is verified that there is a target within the image, the image analysis client saves the information pertaining to the target, and performs georeferencing by calculating positioning information of the camera to determine the location of the target. Once all target parameters are determined the program then saves all the information into a single file.

6.2.4.3Georeferencing
Georeferencing is performed by taking the relative position data of the camera and calculating its field of vision. The positioning information is obtained from the onboard inertial measurement unit (IMU) attached to the camera. By knowing the altitude, latitude and longitude, pitch, role, and attack angles, the center of vision of the camera can accurately be determined. Utilizing this angle information it is also possible to calculate points off from the center of the field of view by calculating the ground angle with reference to the image taken.

6.2.5 Camera Control Client
The position of the camera is controlled via a socket link to the FX12 on the aircraft's payload. The FX12 then controls the positional servos on the gimbal. The position commands for the gimbal are provided by a joystick at the ground control station. By using a joystick for control of the gimbal both the position and rate of change of the servos can accurately be adjusted. The ground server for the servo control also includes an interface to the camera to allow the adjustment of the zoom level which is also communicated to the main GCS server for use in the imaging client. Built in software limits assure that the gimbal never reaches a position in which it might damage itself or become jammed preventing damage to the camera or its mounting structures.

6.3 Data link
Communication to the payload controller is provided over a 802.11n wireless bridge. This provides a direct Ethernet connection to link the FX12 to the ground station software as well as a link to the high definition camera. The Flight Control System (FCS) communicates over a dedicated and separate 900MHz wireless link. The manual flight mode communicates separately over a 2.4GHz link. The wireless bridge payload link and the FCS link operate over a self pointing directional dish antenna assembly providing a stable signal to the ground control system.

6.4 Data Flow Structure
The Data flow structure of the flight system is demonstrated in the diagram below. It summarizes communication between the ground station and the various components of the UAV.


Flight Control System
Servo, Client/Server UDP
Sanyo Camera H264/HTTP
Ground Control Station
Sanyo Software
Live View (HTTP/H264)
Save frames
Zoom
Focus
Control
Receive GPS
Receive IMU
Receive Servo Data
Gimbal Control
Maps
Display Airplane Information
Manual Target
Check Coordinate
Set Shape
Set Letter
Set Color
Save the information in a CSV format.
Automatic Target
AForge
Shape Recognition
Color Recognition
Tesseract OCR
Image to text
Save the information in a CSV format.

6.5 Payload

The payload consists of a high resolution camera a two axis gimbal, inertial measurement unit (IMU), and an embedded computer system for control (FX12). This system allows for stabilized remote target locating.

6.5.1 Camera

The camera is a high definition Sanyo security camera with Ethernet communication providing control and the video link. Camera settings and zoom level can be accessed from the ground station over the commiseration link during flight.

6.5.2 Gimbal

The gimbal allows for over 360 degrees of rotation and over 90 degrees of tilt providing complete coverage of the field of view from underneath the UAV. The gimbal utilizes high torque servos with bearings and all mettle gearing creating a strong and stable platform capable of more than five pounds of payload. The servos were modified for continuous operation to allow for additional gearing to be used to control the platforms. External potentiometers provide feedback to the servo control board allowing the position of the platforms to be directly read and any play in gearing automatically compensated for.

6.5.3 IMU

The Microbotics MIDG I is used to provide feedback of the cameras position and orientation allowing for the calculation of targets in the cameras field of vision. The MIDG I utilizes GPS, three axis accelerometers, three axis gyroscopes, and three axis manometers with built in filtering and sensor integration. This provides reliable readings without drifting over time or errors due to constant acceleration due effects such as long term banking of the vehicle.

6.5.4 Computer Controller

The FX12 embedded computer system utilized for the payload control was designed and built by VCU. It provides a power PC core running Linux on an FPGA creating an enormous amount of flexibility for peripheral control. The FX12 communicates over Ethernet reporting camera positioning information to, and receiving commands from, the ground station. The FX12 also manages communication with the IMU and controls the servo's providing a feedback loop for stabilizing and absolute position pointing. Calculation for the location in the center of the camera's field of vision is also calculated on the FX12 while the targets absolution is calculated at the ground station using this point as a reference.

6.6 Method of autonomy

The UAV runs an in house build flight controller that utilizes GPS and infrared sensors to find it’s position and current angle of attack. Utilizing waypoints sent to it from the ground station it efficiently plans a rout to the waypoints given while adhering to set restrictions set by the pilot such as elevation, maximum banking, maximum and minimum speeds, and approach angles.

7 Safety Considerations and Approach

7.1 Failsafe flight modes

The flight control system incorporates additional flight modes that ensure maximum safety in the event of a system failure. These flight modes can also be activated by the safety pilot or the Flight Control Operator.

7.2 Return Home

The return home system is built into the FCS with its own dedicated components. In the event of failure of the radio link for more than 30 seconds the system will first attempt to return to the home coordinates that were preset before the beginning of the mission.

7.3 Flight Terminate

In the event that not only does the autopilot lose contact, but the separate safety pilot receiver loses its link the aircraft will automatically return to manual control mode, turn off the engine and engage in a low energy spiral as specified in the mission requirements. In this way the mission flight can be terminated at any time by turning off the safety pilot transmitter and the aircraft will terminate. In the same way if the aircraft travels too far from the ground control station and is unable to return within range within 30 seconds the aircraft will self terminate flight.

7.4 Batteries

Battery voltages are continuously monitored by the FCS (and transmitted to the GCS) to ensure they remain in safe operating regions. Safe operating thresholds are calculated based upon the current aircraft distance from the home location, with an additional safety margin. If any battery voltage drops below this safety threshold, the FCS enters Return Home mode. In the event that the flight critical motor batteries become depleted before the aircraft is able to return home, the aircraft will perform a minimum energy landing.

7.5 Failure Modes Analysis

Failure	Response
Loss of RC Communication (Initial)	Ground operators are notified and FCS enters return home mode.
Loss of RC Communication (30 sec)	Aircraft will execute flight termination procedure.
Loss of GCS Communication (30 sec)	Ground operators are notified and FCS enters return home mode.
Loss of GPS Link (Initial)	Aircraft will hold course and minimum safe speed, if the aircraft approaches a no fly zone or otherwise unsafe conditions manual control will be activated by the

	ground control team and the RC Safety Pilot will take control.
Loss of GPS Link (1 min)	RC Safety Pilot will take manual control.
FCS or Receiver battery or fuel level for aircraft falls below minimum level	Ground operators are notified and FCS enters Return Home Mode. Additionally RC Pilot might assume control.
FCS or Receiver batteries or fuel levels fall below critical levels	Aircraft Will Execute flight termination procedure.
FCS battery dies	RC Safety Pilot will take manual control.

8 Proof of Flight Statement

At the time of writing the aircraft has flown three times successfully. Figure 1 shows the aircraft in flight, but due to the lack of video, proof of flight is also certified by the advisor Dr. Robert Klenke.

9 Acknowledgements

The VCU SUAS 2011 competition team would like to thank the following individuals and organizations for their guidance and support throughout this project. Each has unselfishly contributed to make this project a possibility. We would like to extend our sincerest gratitude.

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- VCU School of Engineering