United States Air Force Academy Design Project

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Abstract

The 2009 United States Air Force Academy AUVSI Student Team developed an unmanned aerial system providing the US Marines intelligence, surveillance, and reconnaissance support to meet the needs put forth for the 2009 AUVSI student competition. The team used a systems engineering approach to develop the best possible solution. The three main components the team examined were the airframe, auto pilot, and payload. The Sig Rascal 110 was chosen as the main airframe because of its size and stable flight characteristics. , The team chose the Piccolo autopilot from Cloud Cap Technologies. This is a reliable autopilot and can be interfaced with various payloads. Finally, the team chose a Sanyo VCC-ZM600 camera mounted on a gimbal because of the camera's high resolution and autofocus features. The integration of the air frame, auto pilot, and payload provides a system that offers a bird's eye view of the battle field for troops on the ground.

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* All images of the Piccolo System were acquired through the Cloud Cap Website (ITAR compliance)

Introduction

The United States Air Force Academy (USAFA) AUVSI Team was tasked with developing an unmanned aerial system (UAS) to compete at the 2009 AUVSI UAV competition. The UAS needed to meet some basic requirements including autonomous flight and video capabilities. The USAFA AUVSI Team took a systems engineering approach to best develop a solution for competition. The final system the team developed implemented the Sig Rascal 110 airframe, the Cloud Cap Piccolo autopilot, and a Sanyo camera mounted on a gimbal.

System Description Document / Systems Approach

The USAFA AUVSI team implemented a systems engineering plan centered on the "System Description Document," or SDD. The SDD is a working document released at various points in the course of system design and originated as part of the CORE systems engineering software available from the Vitech Corporation. The document describes everything that has been designed up to the point of a particular release. The purpose of this was to use a systems engineering approach that allowed USAFA faculty and research advisors to have a complete view of the students' progress at any point in the semester. In addition, the SDD was treated as a working document using Microsoft Word. The team was able to save baseline copies at the release points and use the document to track changes and progress. Main sections of the SDD include originating requirements, performance requirements, overall functional behavior model, resources, and system components. Figures and subsections included all system functional flow block diagrams (FFBD's), and subsystems connectivity relationships. Appendix 1 shows the table of contents and list of figures from the final SDD release upon project completion.

In addition to the SDD as a running systems engineering document, the team used Microsoft Project to schedule and track calendar progress for the project. This was initially used to create a baseline plan for the semester, but it did undergo changes as the team made modifications to the requirements and, consequently, the system functionality goals. Appendix 2 shows a high level view of the final schedule at the release date of the final SDD.

The full SDD is included in the team's System Documentation Binder.

Categorization

The SDD and MS Project Schedule were used by the team to monitor, document, record, and implement progress and change to the system. However, the primary systems-based approach used in the design of the project was known as the "spiral" approach. Here certain levels of functionality are designated to a sequential series of "spirals," where each one builds on the previous. The final spiral usually represents a complete system that is ready to be verified and capable of resolving all documented requirements and functionality.

The USAFA AUVSI team originally planned three spirals. However, due to delays experienced in the semester, changes to the system functionality were implemented and the schedule was compressed into two spirals. The justification for this was written up as an Air Force Memorandum-for-Record, originally submitted to USAFA faculty and included here as Appendix 3.

In the team's System Documentation Binder, descriptions of each spiral are provided in greater depth under the "categorization" tab, to include detailed lists of the requirements resolved by each.

Requirement Tracking

To manage and track changes to system requirements (to include originating and derived requirements), the team used the aforementioned SDD. Originating requirements were defined, listed, and linked to various points of functionality. The subsequent functional flow was compared to the AUVSI competition problem description, safety needs, and mission parameters. Newly derived requirements were established to ensure that these original requirements were met and that functional blocks were as simple as possible. As the SDD is a working document, it was possible to establish, derive, analyze, make changes to, and track changes to all of our requirements within the document itself. The establishment of baseline documents allowed all changes to be seen and undone if necessary.

The SDD architecture also allowed for various documentation linkages to all requirements. Categories, which described the spirals, encompassed all of these requirements. Requirements were also labeled using a “refines” / “refined by” description which linked them to other specifications, allowing for the creation of a hierarchy which broke high level requirements down into smaller derived units. Next, these were labeled as the “basis of” functional points of the system. This gave the team a clear view of which subsystems resolved which requirements, subsequently making it easier to schedule work for each spiral.

All of these relationships and hierarchies are described in greater detail in the “Requirements” tab of the USAFA team’s System Documentation Binder.

System Overview

1. System Components

a. Air Vehicle

The team chose to use the Sig Rascal 110 as the airframe for the competition. The Rascal is a quarter sized RC aircraft with room for both a payload and autopilot. Additionally, the Rascal 110 has relatively stable flight characteristics, making it an ideal choice for this competition. The Sig Rascal has a wingspan of 110 inches, a wing area of 1522 square inches, and a wing loading of 16.6 oz- square foot. The airframe weighs approximately 13 lbs. The control surfaces of the Rascal 110 are controlled by JR brand digital servos. In total four servos are used: two for the ailerons, one for the elevator, and one for the rudder.

Figure 1 (www3.towerhobbies.com)

We used a Hacker C50 10XL electric motor as the power plant. The team chose to use an electric motor because it is more efficient at high altitude and it is cleaner running. Electric motors are easier to store than gas engines because one does not have to adhere to the hazmat regulations associated with storing fuel. Another advantage to using an electric motor is that it can be easily turned off and on. The Hacker C50 10XL uses a Hacker Master Spin 99 Opto speed controller. The speed controller allows for variable rpm of the motor in flight.

Lithium-Polymer batteries power the servos and electric motor. The batteries are rated at 5000 mAh at 18.5 V. Two of these batteries wired in series power the Rascal 110. They are in series because the motor needs 40V to produc enough power for takeoff. The two Lithium-Polymer batteries will provide about 35 minutes of flight time. The autopilot and camera are powered separately using a 2000 mAh 12 V Lithium-Polymer battery each. These batteries can power the autopilot and camera up to two hours.

b. Sensor System

The team used the Sanyo VCC-ZM600 as the main camera on board. The Sanyo has a 30 X zoom lens along with an auto focus feature. The auto focus is a key component for the system since the altitude of the plane will be continuously changing. The camera is mounted underneath the Rascal 110 on a custom built gimbal device. The Engineering Mechanics lab at the United States Air Force Academy designed and manufactured the gimbals device for the AUVSI Team.

The video data is transmitted to a ground station using a Black Widow transmitter and receiver system. This system uses a 2.4 GHz frequency band to transmit the data. A small antenna is located inside the Rascal 110 and a larger directional receiver antenna is located on the ground. The video feed is transmitted to a laptop computer which runs a multipurpose program developed in house for this and other USAFA research. The program accomplishes many different tasks. First the program keeps the camera at a perpendicular orientation to the ground during unsteady flight or while the aircraft is in a bank. To accomplish this, the program determines the bank of the aircraft and adjusts the gimbal of the camera. The program also runs through a network connected to the Piccolo Command Center to retrieve telemetry data of the aircraft in flight. The program pairs the telemetry data with images captured from the video stream. This gives a location and orientation of the photo. Once a flight is over, these images, paired with telemetry data, are saved to a database. These saved images can then be overlaid on Google earth. The ability to overlay images provides the ability to get an exact GPS location objects in the image. Path of the data is shown in Figure 2.

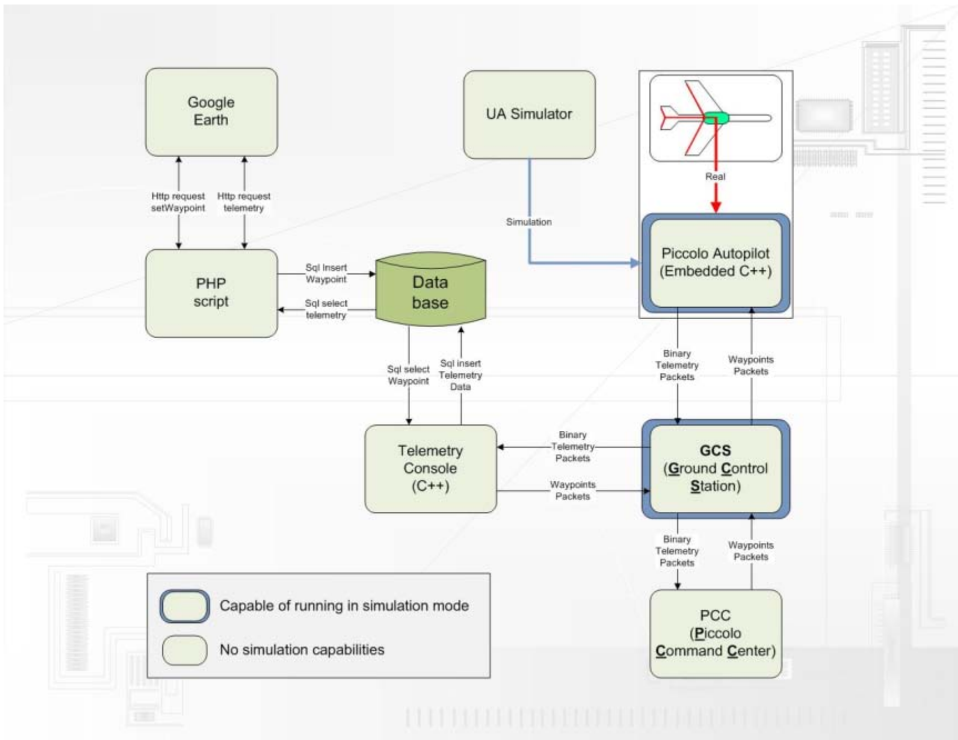

Figure 2

c. Auto Pilot System

The team chose to use the Cloud Cap Piccolo autopilot system to provide autonomous flight. The Piccolo was used because it has been operational in many of the US Military's UAVs and it has the capability to integrate with other software. This integration is important because the gimbal reacts to the orientation of the plane. The entire Piccolo system is broken down into three main parts, the onboard autopilot, the Piccolo ground station, and the Piccolo Command Center software.

The onboard Piccolo that the team is using is shown in to Figure 3. The Piccolo has inputs for a pitot tube and static tube. These inputs are used to calculate the speed of the aircraft using differential pressures. The autopilot has a connection for a GPS antennaused to determine the location of the aircraft. Also, the Piccolo has internal accelerometers used to determine the pitch, roll, and yaw of the aircraft. Finally the onboard autopilot has a harness that provides servo inputs allowing the Piccolo to control all aspects of flight with little or no human interaction.

Figure 3 (www.cloudcaptech.com)

The second part of the Piccolo autopilot system is the ground station. The ground station provides a relay point between the onboard Piccolo and the Piccolo Command Center. The ground station sends and receives information from the onboard Piccolo using a 900 MHz signal. It is connected to a Futaba 6 channel remote control for manual control providing a RC pilot the ability to take control of the aircraft during flight.

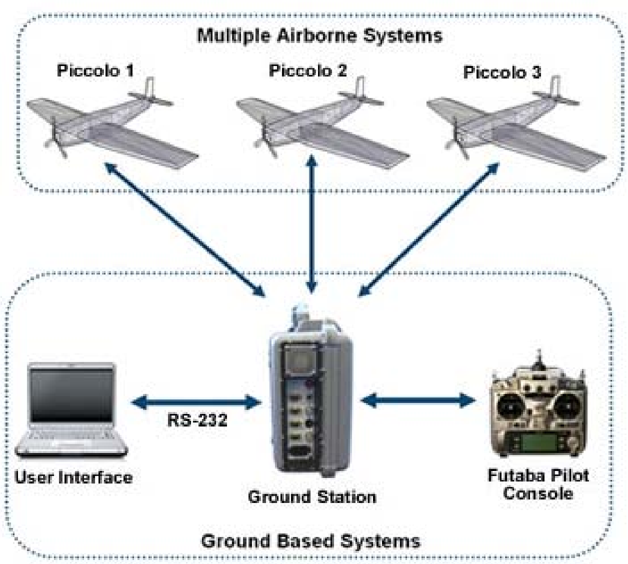

Figure 4 (www.cloudcaptech.com)

The third part of the Piccolo autopilot system is the Piccolo Command Center (PCC). The PCC is the software that runs the entire Piccolo system. The software is loaded on a Dell D600 laptop with Pentium Processors. The PCC allows users to create flight paths for aircraft, observe the orientation of the aircraft, and view the area of operation. In Figure 5, you can see the heads up display in the lower right hand corner of the screen. This provides the heading, altitude, airspeed, pitch, and roll of the aircraft. This is important for PCC operator to monitor because it will indicate if there are any problems with the aircraft. The PCC can run multiple UAVs, however, this greatly increases the complexity of the operation. The USAFA Team has only flown one UAV at a time.

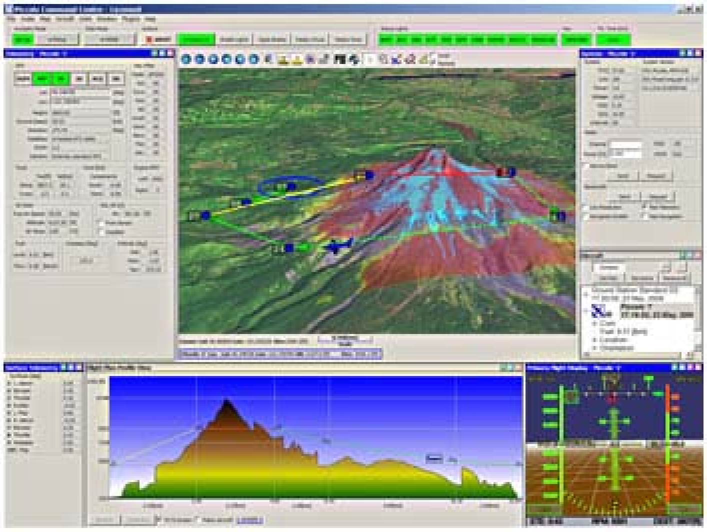

Figure 5 (www.cloudcaptech.com)

d. Safety System

The USAFA AUVSI Team implemented two different safety systems into their UAS system. The first safety system is a lost communication waypoint. which is a preset location in the PCC. If the UAS loses communication with the ground station for more the five seconds the UAS will automatically start tracking the lost communication waypoint until communication is reestablished with the ground station. Also if communication is not regained within a predetermined time the UAS will go into a controlled crash by putting the plane into a spin.

The second safety system used is a safety board. The safety board gives a safety pilot on the ground the ability to take control of the aircraft at anytime using a regular 72 MHz RC controller. So if the UAS is not performing as it should, the safety pilot can take control and fly via remote control plane. Also, the safety board will automatically give control to the safety pilot if the battery for the Piccolo fails. The safety board is a better solution than the Futaba radio connected to the Piccolo ground station because the response is instantaneous and the controls are more responsive. The safety board is designed and built by the Electrical Engineering Department at the Air Force Academy.

2. Resources

The USAFA design team for the 2009 AUVSI competition consisted of eight undergraduate students. However, due to graduation and commissioning in the Air Force, not all of these students were able to attend. This in mind, only three members of the team were guaranteed to be able to act as system operators. These three operators were categorized as resources throughout the design of the system. Operator one performs the pre-flight checklist, manual takeoff, transition to autonomous flight, observe flight, transition to manual control, execute landing, and power down system. Operator two performs pre-flight checklist, power up of aircraft, ground control station, and sensors, monitors the PCC. Operator three performs pre-flight checklist, power up the network, monitors video feed, identifies targets, and reports target information.

System Verification

The USAFA student team tested all the systems multiple times in the lab using simulation software. The simulation software provides a virtual environment for the autopilot to operate. The autopilot has to correct for winds, altitude changes, and course changes. This was instrumental in determining if the aircraft was configured correctly. The team would not fly a mission without testing the Piccolo in a simulation first. The team also used the simulated telemetry data to test the computer program that paired the video feed with the telemetry data. On May 20 2009, the USAFA student team successfully tested the entire UAS system. The UAS flew autonomously and was able to collect video data.

Conclusion

After a semester, the USAFA AUVSI Team developed a UAS that implemented the Sig Rascal 110, Piccolo autopilot, and Sanyo Camera. With all of these systems working together the USAFA UAS has the ability of flying autonomously and gathering video data with GPS coordinates. The current UAS will accomplish the basic requirements of flying autonomously, recognizing targets, giving their shape, orientation, color, and alphanumeric. The system also has the ability of giving rough GPS location of the target. Overall the USAFA Team feels that they should be competitive in the AUVSI competition.

References

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Lotspeich, James. Personal interview. Spring 2009.

"Rascal 110." Sig Manufacturing . 25 May 2009 <http://www.sigmfg.com/>.

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2009 Student UAS Competition. 25 May 2009 <http://www.navair.navy.mil/pma263/seafarers/journal/journal.html>.

The team would also like to acknowledge and thank the Electrical Engineering Department and the Computer Science Department at the Air Force Academy for all of their support.

Appendix 1

Wednesday, May 06, 2009

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Appendix 2

	Task Name	Physical % Complete	Duration	Start	Finish
1	**− Spiral One**		**16 days**	**Fri 01.09.09**	**Fri 01.30.09**
2	Aircraft Construction	100%	16 days	Fri 01.09.09	Fri 01.30.09
3	Piccolo Installation	100%	16 days	Fri 01.09.09	Fri 01.30.09
4	Stable Flight (manual and auto modes)	100%	16 days	Fri 01.09.09	Fri 01.30.09
5	Streaming Video System	100%	16 days	Fri 01.09.09	Fri 01.30.09
6	Initial SDD Delivery	100%	23 days	Fri 01.09.09	Tue 02.10.09
7	**− Spiral Two**		**61 days**	**Wed 02.11.09**	**Wed 05.06.09**
8	Spiral Two Functional Description	100%	1 day	Wed 02.11.09	Wed 02.11.09
9	Initial Search Method	100%	28 days	Wed 02.11.09	Fri 03.20.09
10	Video System Installation	100%	28 days	Wed 02.11.09	Fri 03.20.09
11	Video Capture	100%	29 days	Fri 03.20.09	Wed 04.29.09
12	Finalize / Integrate Search Method	100%	8 days	Mon 04.27.09	Wed 05.06.09
13	Implement Geo-Reference System	100%	8 days	Mon 04.27.09	Wed 05.06.09
14	**− Operational Test and Demonstration**		**1 day**	**Thu 05.07.09**	**Thu 05.07.09**
15	Test Description Documentation	100%	1 day	Thu 05.07.09	Thu 05.07.09
16	Final SDD Release	100%	62 days	Wed 02.11.09	Thu 05.07.09

DEPARTMENT OF THE AIR FORCE

6 May 2009

MEMORANDUM FOR RECORD

FROM: C1C Charles Neal

SUBJECT: Documentation for Change to Spiral Plan

1. The purpose of this memorandum is to document and describe the change from the baseline plan of three spirals, with the option to add a fourth (at team discretion) to the final plan of two spirals.

2. The baseline plan for the UAS development for the 2009 AUVSI student competition was originally documented in January of 2009. This plan allocated the functional requirements of the UAS into three spiral deliveries. Each spiral encompassed an increased level of system functionality, with the third spiral representing full ability to compete in the student competition. In addition, the option to extend into a fourth spiral was defined. This spiral would have been at team discretion for the pursuit of resolving non-mandatory system functionality.

3. The plan has deviated from this baseline into a two spiral project. This is because of time delays throughout the cadet semester. The causes for these delays are twofold. First, the process to obtain USAF certification to fly our aircraft in class G airspace took longer than expected, resulting in a period of time during which we could not fly. Second, extended periods of bad weather prevented flight operations even after USAF certification was achieved. The product of not being able to fly was an inability to complete some of our subsystem integration and lack of ability to meet functional delivery dates laid out in version one of our project schedule.

4. The end result of these delays is a deviation from three spirals to two. The required system functionality was appropriately amalgamated into the final spiral release, spiral two. In addition, the team will not be pursuing an additional spiral for non-required functionality. Time between the spiral two delivery and the student competition will be spent in operational testing and practice for the operators.