University of Kentucky Aerial Robotics Team: 2007 AUVSI Student UAV Competition Design

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Abstract

The University of Kentucky unmanned aerial vehicle (UAV) system designed for the 5th AUVSI Student Competition is based on off-the-shelf aircraft technology and flight control with custom electronics designs for payload control. The airframe chosen is high-wing design with autonomous control, high-bandwidth communications and live video feed for target recognition. It was designed in senior design courses and engineering technical electives in Spring 2007 by students and faculty in Electrical and Computer Engineering Department, Mechanical Engineering Department and Department of Computer Science at the University of Kentucky.

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1 Introduction

The University of Kentucky Aerial Robotics Team unmanned aerial vehicle (UAV), Southern Komfort, was designed during the 2007 Spring Semester for the Fifth Annual AUVSI Student Competition and is based on designs from our previous entries to this competition. The system was designed by senior undergraduate students from the Department of Electrical and Computer Engineering and the Department of Computer Science. This paper documents the development of the airframe and sub-systems, a live video feed based target recognition approach, and integration of the airframe with an autopilot system.

This project is part of an ongoing effort at the University of Kentucky to develop technologies for autonomous aircraft as they apply to space exploration, scientific research, and defense applications.

Figure 1 – UK Aerial Robotics Team

2 Overview

The UK Aerial Robotic UAV, pictured in Figure 2, consists of several subsystems. These onboard systems include an autopilot, a microcontroller system controller, camera used for the recording of the high-resolution photographs of the targets, and camera stabilizer.

The UK Aerial Robotic UAV has included on it an 8-bit microcontroller from Silicon Laboratories running the μC OS II real-time embedded operating system. This microcontroller's purpose is to capture the autopilots telemetry and record GPS latitude, longitude as well as the pitch and roll of plane in flight. These parameters are overlaid onto the video feed of a color camera that is transmitted on a 70 cm frequency in the amateur radio television (ATV) band using an of the shelf transmitter. The microcontroller system also uses the attitude information to control the two axis motorized camera mount for stabilization.

The ground control software creates the flight plans that are relayed to the autopilot. The Cloud Cap Technologies Piccolo II autopilot maintains basic control of the aircraft and carries out flight plan sequences issued from the ground station software. The Piccolo is a powerful autopilot with an integrated pitot-static system and GPS receiver that is capable of both relative navigation and absolute GPS coordinate navigation. The ground control software displays the location of the aircraft on map images and translates flight plans based on GPS coordinates derived from the map data. The graphical map data is displayed on the main control console of the ground control station software and provides an intuitive mission planning interface.

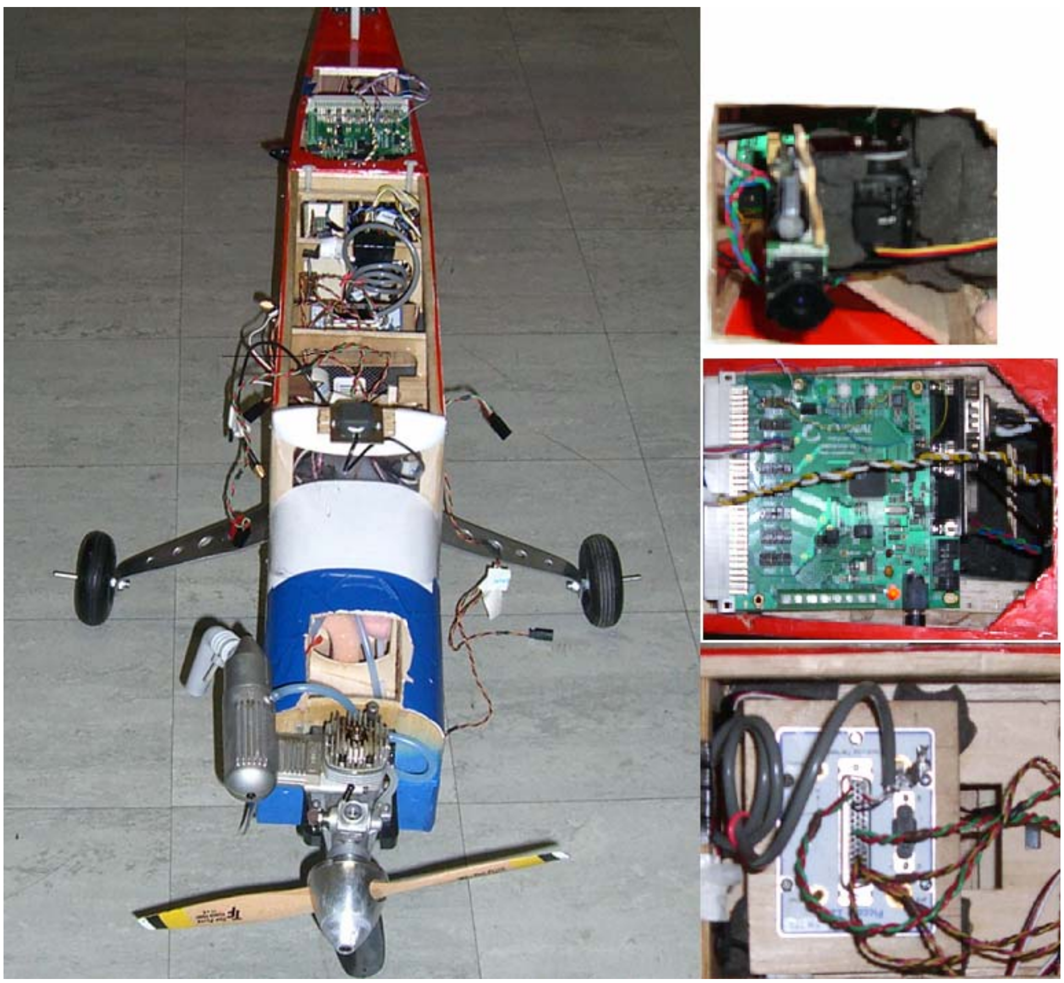

Figure 2 – Southern Komfort UAV (left) and Camera (top right), Camera Control (middle right), Autopilot (bottom right) Subsystems

3 Design

3.1 Airframe

The airframe for the competition was selected with several requirements in mind. The airframe needed to be low cost so that the team would be able to purchase components to construct multiple complete platforms. Utilizing multiple airframes allowed for parallel development within the airframe design and testing phases. The second requirement was that each airframe needed to be assembled quickly. Given these first two requirements, the aircraft must also perform well in the air, meaning that it needed to provide a stable platform for image requisition and waypoint navigation.

Figure 3 - Sig Manufacturing Kadet Senior

The solution chosen to fit these requirements is a radio controlled airplane, the Kadet Senior from Sig Manufacturing, shown in Figure 3. This low-cost aircraft allowed for several airframes to be purchased for development. This model is available in an ARF [Almost Ready to Fly] form that minimized basic assembly time. This model has a high-wing design with a relatively large wing area of 1180 sq. in., and light balsa-plywood construction giving the airframe an unloaded weight of 6.5 lbs (without engine). This design makes the aircraft naturally stable, while also carrying a relatively large payload and still being able to fly adequately slow for image reconnaissance.

The Kadet Senior airframe was modified from its original design. All servos were removed form the inner cabin and repositioned near the respective control surfaces providing a larger central payload area. Mounts for the autopilot, processor and camera were added within this payload area.

The power plant of the aircraft will consist of an AXI 4130/20 motor with a Jeti Advanced PLUS 77 Amp Opto brushless controller. The weights of these components are 14.42 oz and 1.375 oz respectively. Finally the battery pack used to power both devices will be an 8 series, 2 parallel 4000mAh pack weighing 21.9 oz. Using this setup, propeller rotation speed is approximately 7000 RPM at full throttle. At this speed, flight time will range from 10 to 15 minutes.

3.2 Autopilot

The Piccolo II Autopilot system from Cloud Cap Technology, Inc was selected for the competition. This system, shown in Figure 4, includes the autopilot hardware including a GPS receiver, an inertial measurement unit, PID control loops for aircraft stabilization and GPS navigation, and an integrated Microhard Systems Inc. MHX 910 serial data radio. The system comes integrated into a single package with dimensions of 4.8" x 2.4" x 1.5" and a weight of 8.22 ounces. The system accepts 8-20 VDC power input. Nominal power consumption is approximately 300 mA @ 12 VDC input. Capabilities of this unit include autonomous operation with catapult launch and automatic landings, dead reckoning and graceful degradation for compensation due to loss of GPS, and manual flight modes.

The MHX 910 is a 900 MHz serial data radio with a transmit power of 1 Watt and a sensitivity of -108 dBm giving it range of up to 60 miles line of sight with data rates of up to115.2 kbps.

Figure 4 - Piccolo Avionics Unit

3.3 Ground Station

The ground station block diagram is shown in Figure 5. The ground station system consists of the Piccolo Ground Station hardware and the Operator Interface Software, running on a PC or laptop, connected through a RS-232 communications link.

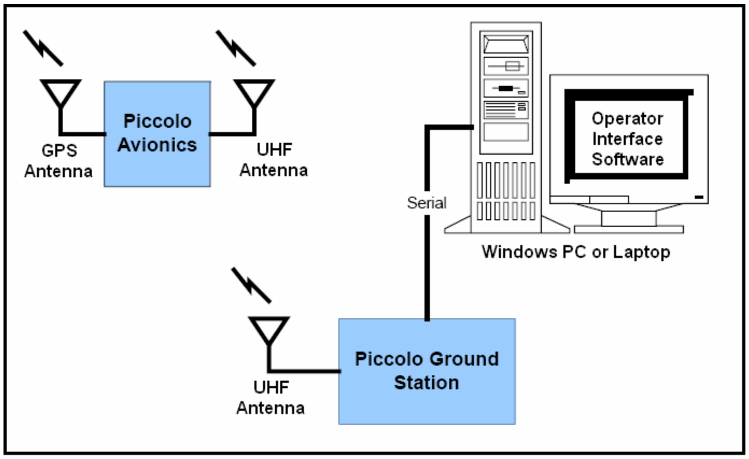

Figure 5 - Piccolo Block Diagram

The Piccolo Ground Station hardware consists of a Microhard Systems Inc. MHX 910 serial data radio, a GPS receiver, and a manual R/C flight controller interface integrated into a single package shown in Figure 6. The hardware manages the communications between the user PC and the autopilot hardware. The R/C flight controller adds a pilot in the loop capability allowing a human to take over control of the aircraft at anytime. The ground station hardware can be powered with either 120VAC using the included adaptor or by using a 12V car battery.

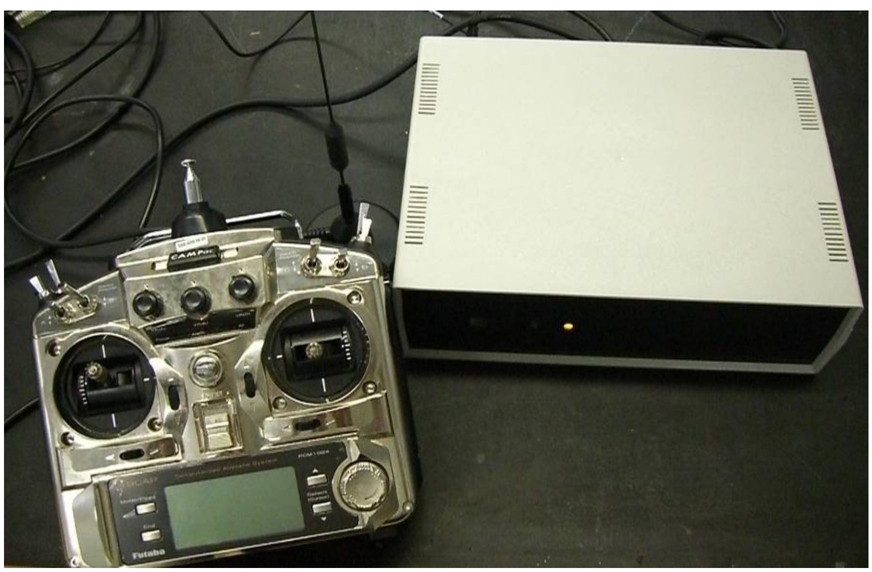

Figure 6 – Piccolo Ground Station Hardware

The Piccolo Operator Interface software, shown in Figure 7, runs on a Windows PC and is connected to the Piccolo ground station via a serial port. The Operator Interface is the interface between the user and the Piccolo hardware. The interface displays the autopilot telemetry which includes attitude, speed, altitude, GPS location, and flight plan. It also gives the user the capability to create and edit flight plans, calibrate control surfaces and sensors, set in-flight autopilot limits for airspeed and attitude, and to define flight termination procedures in the event of communication or GPS system failure.

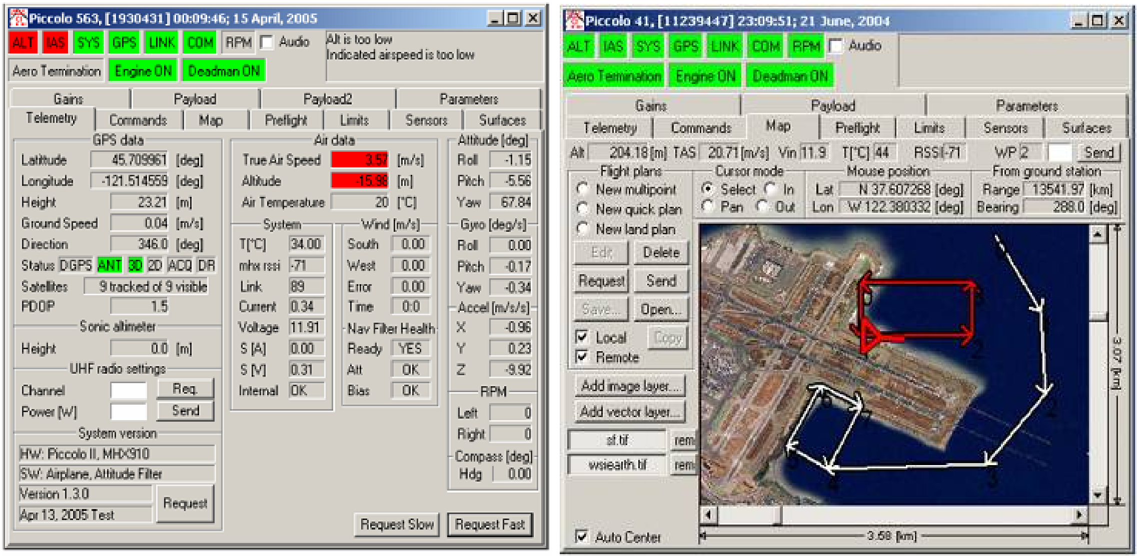

Figure 7 - Piccolo Operator Interface Screenshots

4 Camera System

The camera payload system block diagram is shown in Figure 8. The power system will use two 9.6V Ni-Cd rechargeable batteries for delivering adequate power to all parts of the payload system. The power systems will provide 12V, 5V, and 3.3V rails through the use of three low drop out (LDO) regulators providing the needed voltages. Although using an LDO regulator is perhaps not the most efficient method for power conservation, the time constraints and complexity regarding a different method prohibits their consideration. For maximum power conservation, the flight computer will control the power regulated to all of the other devices. Most importantly it will control the power supplied to the ATV transmitter which consumes 24 watts at max output. The flight computer model, C8051F040 from Silicon Laboratories, is one of the main processors used in the IDEA Lab so it was selected as the flight computer for the blimp. If price was the only deciding factor for selecting a processor, a processor such as a Microchip PIC would suffice, but since it was possible to select a processor in a previously familiar development environment (IDE) such as Silicon Laboratories, it obviously makes more sense to chose the latter.

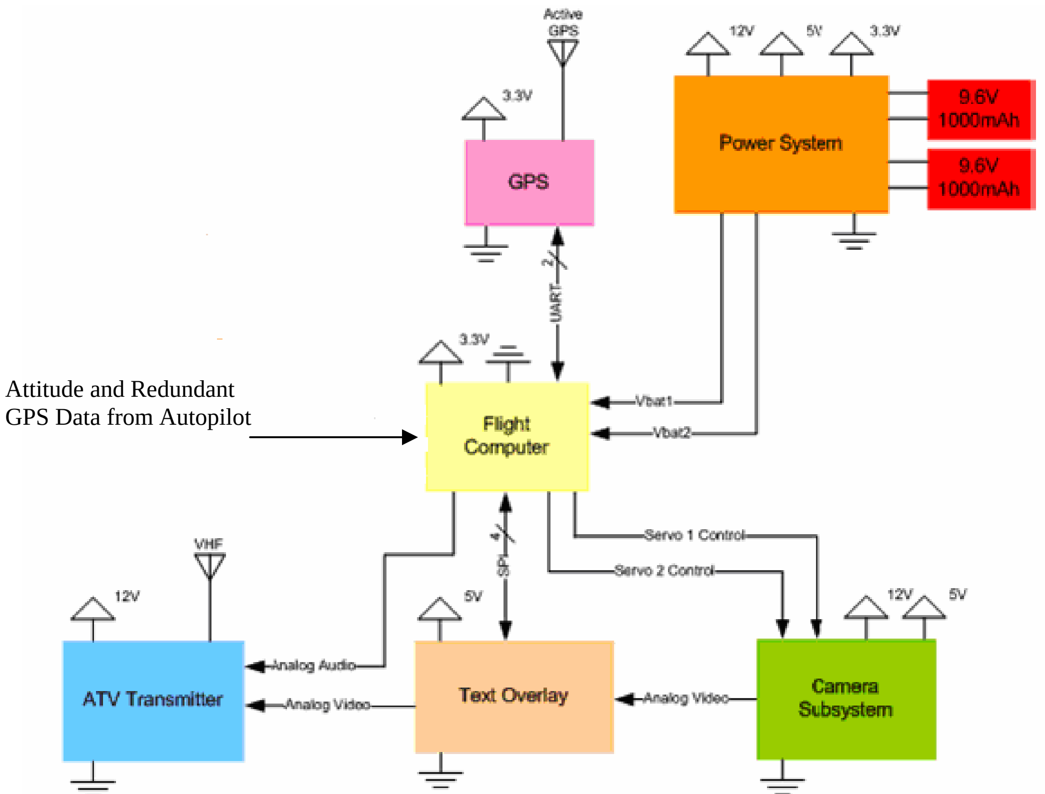

Figure 8 – Camera payload block diagram

Due to the complexity and time required to design a GPS sensor, the Lassen iQ GPS sensor from Trimble was chosen as an off the shelf module that provides real time highly accurate longitude, latitude, and altitude information. The Lassen iQ GPS sensor is the smallest in weight and consumes an ultra low power amount of 86mW, smaller in comparison to any other Trimble products on the market. Due to the higher data output rate compared to the autopilot's output, the data from this GPS will be overlaid onto the video feed. The Sony PC241XS HQ1 Color Board Camera was chosen as the onboard camera, which produces 525 lines of resolution seen from a 3.6mm lens. It has also been customized with two HiTech HS-322HD Deluxe Digital Servos that provide a bidirectional 180° field of rotational freedom for camera stabilization.

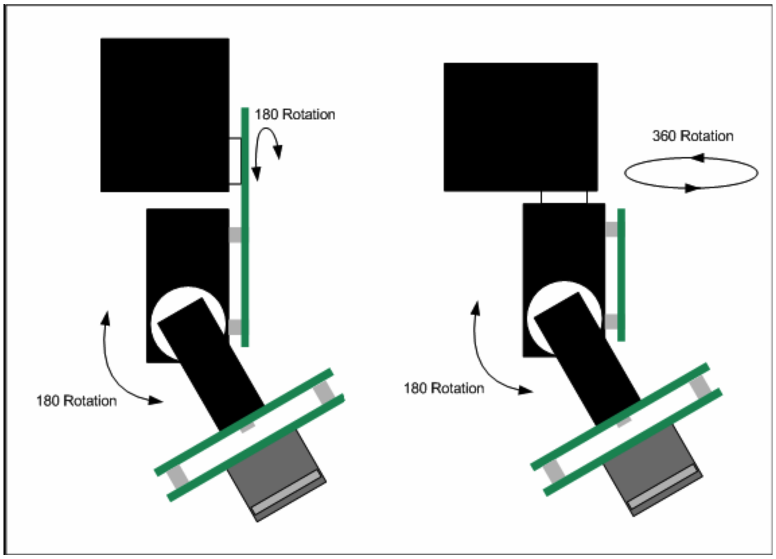

Figure 9 – Camera Mounting

As shown in Figure 9, the desired pan and tilt features are acquired through the combination of these two digital servos and Sony camera acting as a gimble. The gimble on the left was assembled with two 180^{o} servos and has been chosen despite the gimble on the right that provides 360^{o} of rotation. These servos were free and have been modified to enable all necessary camera movements. Finally, having the capability to interchange the 3.6 mm lens with larger lenses up to 25 mm in size, the camera subsystem is able to obtain all desired fields of view for any altitudes at which the aircraft will operate.

The off the shelf module BOB-4 text overlay module was chosen because it is a low-cost video information overlay module that allows a corresponding microcontroller or PC to display text on standard TV monitors. This module generates background video on-board combined with printable characters and commands controlled through SPI or RS-232 style data links. Both NTSC and PAL video standards are supported by BOB-4. BOB-4 has dimensions of 3.50 x 1.05 x 0.35 inches and weighs about 0.35oz. Ambient operating temperature range is 0-50C.

The MFJ-8709 5W ATV Transmitter module was chosen to accept an NTSC video signal and generate a corresponding RF signal modulated with all combined components of the payload system. The signal can be received on any standard TV receiver fitted with a suitable RF down-converter capable of tuning to the desired frequency. Also, a built in video and audio test signal generator is provided for testing purposes and at max output consumes 24 watts. The power output of the transmitter can be adjusted, making it feasible for the payload system on the aircraft. This ATV transmitter sends video using the 70cm amateur radio band.

Section 1.6.3 – Ground Station

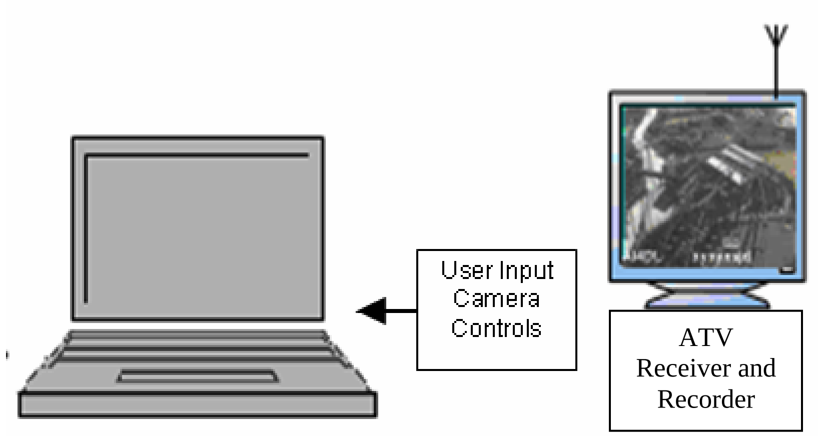

Figure 10 – Ground Station overview

The ground station shown above consists of an amateur TV receiver and display to show the captured video by the payload. In addition, overlaid sensor information, a laptop and radio transmitter to send/receive commands to and from the payload are also shown. The amateur TV signal generated by the camera system can be received on any standard TV receiver fitted with a suitable RF down-converter capable of tuning to the desired frequency. In this case, the ATV receiver is integrated into the laptop. The TV tuner card receives the National Television System Committee (NTSC) color television standard video signal broadcast by the ATV transmitter aboard the aircraft, and must have a composite RCA Video output for use with the head mounted display unit.

The live video feed is recorder on the ground for post flight manual target recognition. The GPS information overlaid on each frame represents the center point of the image. Depending on the target location and orientation in a frame, the actual target parameters will be computed using a prepared custom spreadsheet application.

5 Flight Testing

5.1 Simulation

A key feature of the Piccolo system is the ability to simulate the behavior of the airplane using a hardware-in-the-loop simulator. This allows testing of the flight plans and control loop gain settings without unduly endangering the hardware or airframe. The simulator software communicates with the Piccolo system via the CAN bus. The Piccolo receives telemetry data from the simulator software and outputs servo information to the CAN bus. The simulator software uses a data file with the airframe parameters to predict the behavior of the airframe during flight. The Flight Gear visualization software provides an intuitive display of the attitude of the aircraft during flight. Various flight termination parameters, including lost communications, were verified using the simulator software. It is possible to practice manual flight of the aircraft as well, using the manual pilot override feature of the Piccolo system. The simulator test setup block diagram is shown in Figure 11.

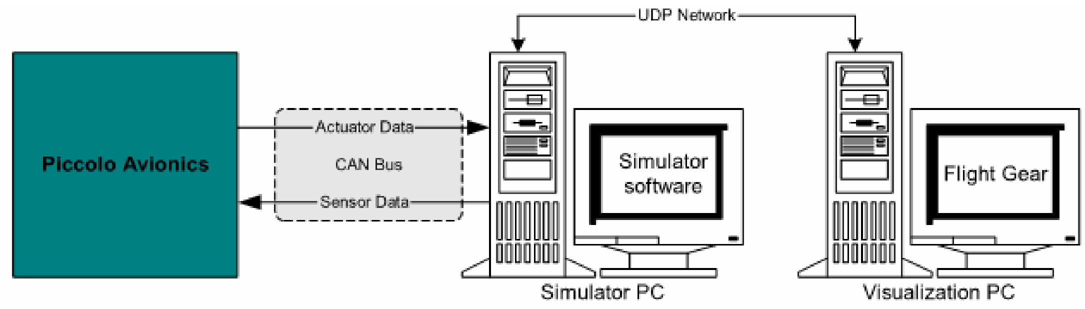

Figure 11 – Hardware in the loop simulation[3]

5.2 Flights

To date the Southern Komfort system has made several successful test flights. These tests include manual takeoffs transitioning to autonomous flight, waypoint navigation, and autonomous landings. The camera control system has been tested and verified functional.

6 Safety

Southern Komfort was designed with high safety margins to avoid in flight structural failure and was inspected by experienced model airplane pilots. All landing gear is over sized to withstand hard landings. To prevent linkage failures from high dynamic pressures during flight, servos are oversized by a factor of 2+. In case of a communication or autopilot failure, the servos are programmed to orient the aircraft in a gentle downward spiral with throttle at lowest setting. In the case of communication loss the autopilot will fly the aircraft to a predefined waypoint to regain communications, if communications is not regained the autopilot will lower the engines throttle and bring the aircraft down under a controlled spiral decent. In the case of GPS loss the autopilot will lower the engines throttle and bring the aircraft down under a controlled spiral decent, as well.

Another part of safety is the operating the aircraft. Flights plans are always tested in simulator mode before a flight this ensures proper aircraft functionality before risking faulty flight. Several in lab practice flights have ensured each team member knows their responsibilities during preflight, flight, and post-flight, leading to a much safer flight field environment.

7 Summary/ Current Status

The University of Kentucky Southern Komfort has completed several successful autonomous flights and landings. The camera control system has been tested successfully. Manual takeoff is still necessary, due to the lack of support for this feature in the autopilot system.

8 Acknowledgements

The University of Kentucky Aerial Robotics Team would not be possible without our dedicated student members, faculty, and sponsors. Lead by Dr. James Lumpp and Dr. Osamah Rawashdeh, this organization operates primarily on the assistance provided by the Kentucky Space Grant Consortium (KSGC). Thanks also need to be extended to RJ Corman for allowing the team to use the Lucas Field Airport, along with Silicon Laboratories and PCBExpress for discounts and donations of microcontrollers and PCB board development.

9 Bibliography

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