University of Kentucky Aerial Robotics Team: 2006 AUVSI Student UAV Competition Design

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Abstract

The University of Kentucky unmanned aerial vehicle (UAV) system designed for the 4th 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 state-of-the-art image processing for target recognition. It was designed in senior design courses and engineering technical electives in Spring 2006 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 2006 Spring Semester for the Fourth Annual AUVSI Student 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, ground-target photo-stitching software, 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 then stored into flash using a custom file system for on ground information retrieval. This controller also has a camera task which is used to control camera functionality such as the powering on and taking of pictures. This task also synchronizes the current GPS information at the time which the picture is taken.

The synchronization of GPS information with each individual picture is important information which is sent out over a serial connection once the plane is on the ground and is formatted into a text file. This text file is then interpreted by our custom photo stitching software that then correlates the pictures based upon their heading and GPS locations.

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.

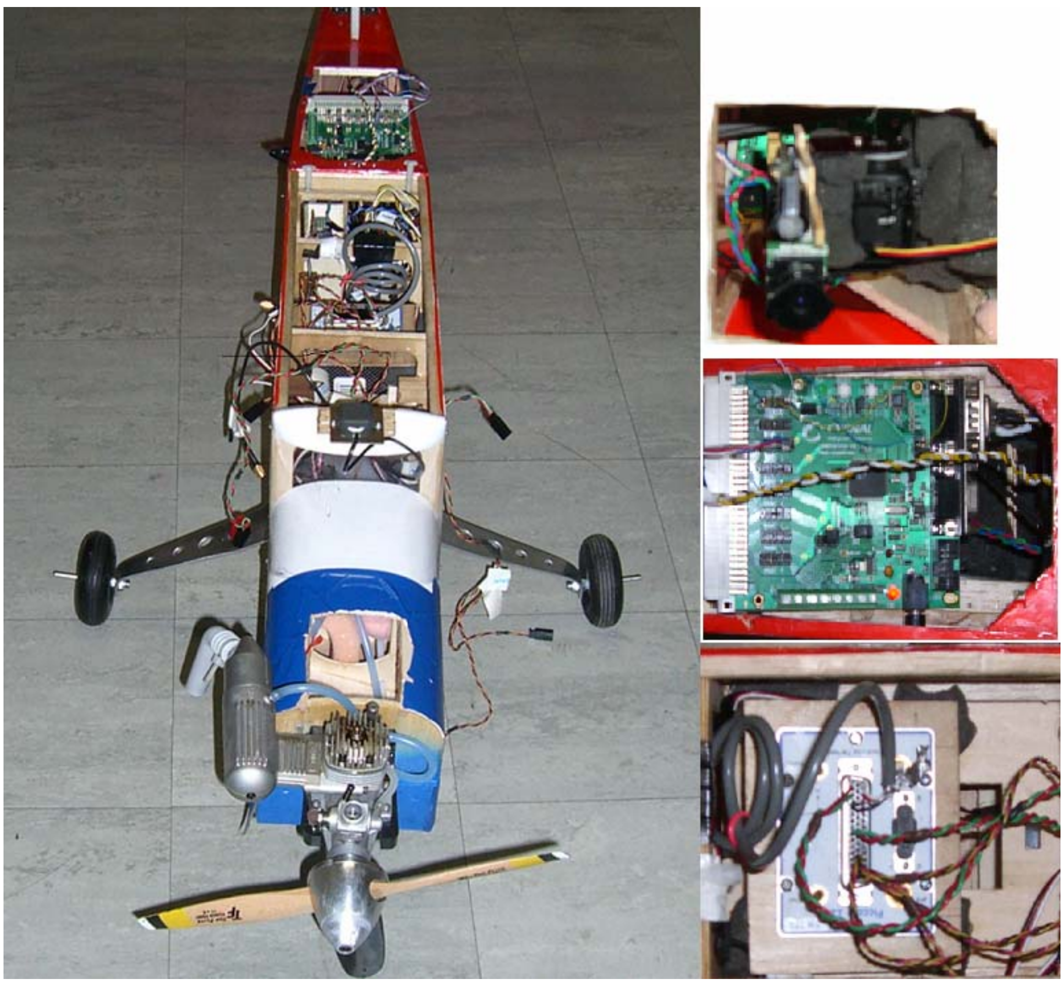

Figure 2 – Southern Komfort UAV (left) and Camera (top right), Camera Control (middle right), Autopilot (bottom right) Subsystems

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. A 16 oz fuel tank was added increasing the airframe's potential flight time to over 30 minutes. Finally, the engine selected to power the airframe was an O.S. .50 SX Ringed glow engine. This engine provides 1.8 bhp @17,000 rpm at a weight of only 13.76 ounces.

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.

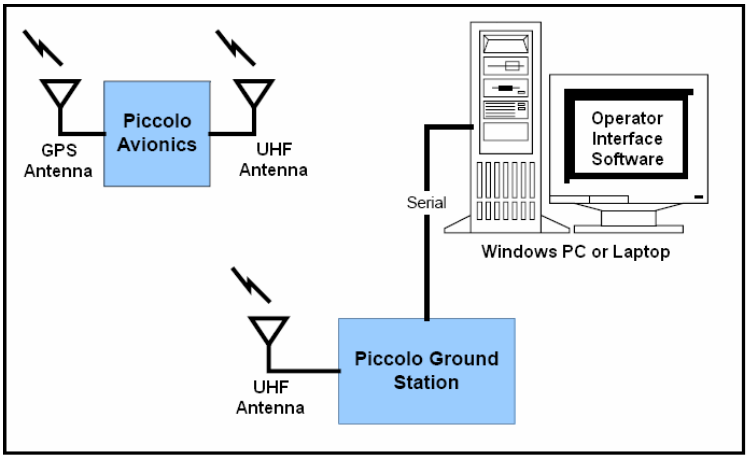

Figure 5 - Piccolo Block Diagram

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.

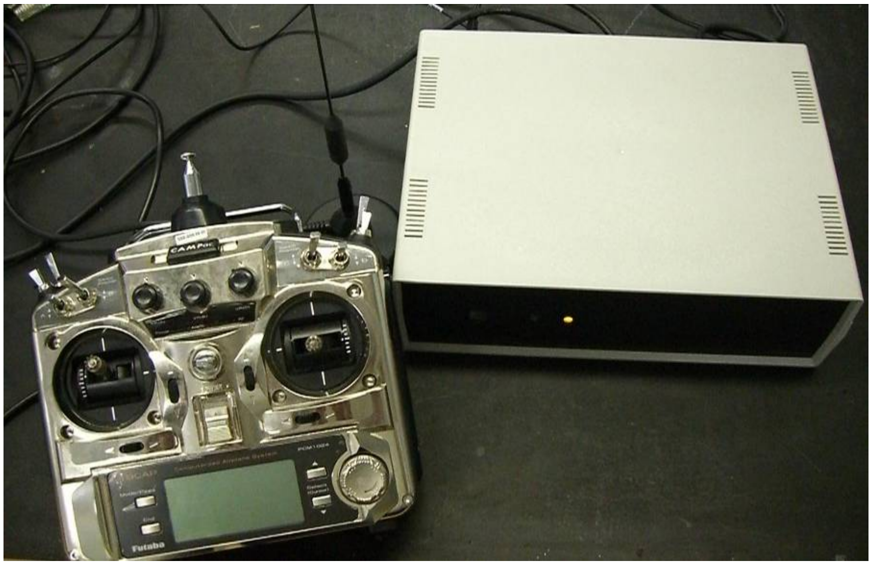

Figure 6 – Piccolo Ground Station Hardware

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.

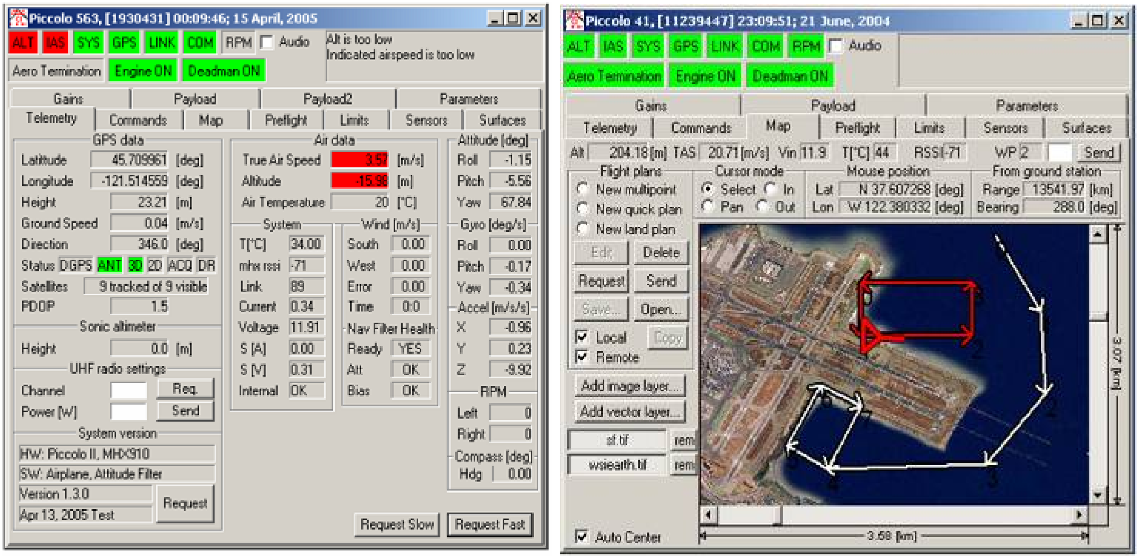

Figure 7 - Piccolo Operator Interface Screenshots

4 Camera System

4.1 Camera/Control

In order to provide high-resolution images, the aircraft is equipped with an Aiptek IS-DV digital camcorder. It provides 3MPixels at 2048 x 1536 pixels resolution and 1GB SD card storage. The cameras push-buttons are interfaced directly to a Silicon Laboratories C8051F040 microcontroller development board for ease of use. Figure 8 shows the microcontroller and the camera.

The microcontroller is running the µC OS II real-time operating system and is used to control the camera as well as parse autopilot telemetry. The microcontroller commands the camera to take pictures at a rate of 4 Hz. Each time a picture is taken that pitch, roll, yaw, altitude, latitude, and longitude is stored in Flash memory for post processing the images.

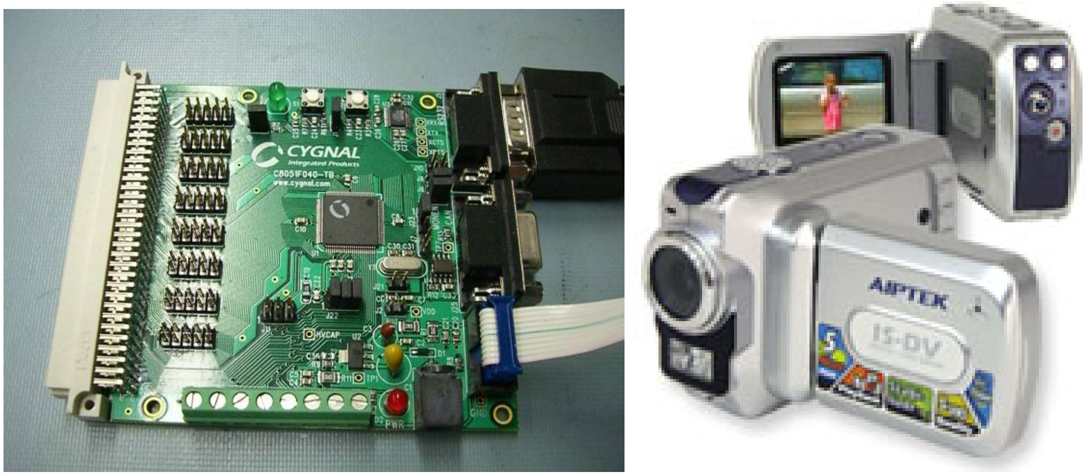

Figure 8 – Microcontroller and Camera

The camera is mounted to the airframe using a pan and tilt assembly produced by Phidgets USA and shown in Figure 9. Two Hitec HS322 servos receive control signals from the microcontroller. The microcontroller holds the camera pointed at the ground counteracting the pitch and roll of the aircraft.

Figure 9 – Stabilization System

4.2 Stitching

Images taken during flight are processed and presented for human/visual analysis and target recognition. Figure 10 is a block diagram representing the logical flow of data and processing performed on the images.

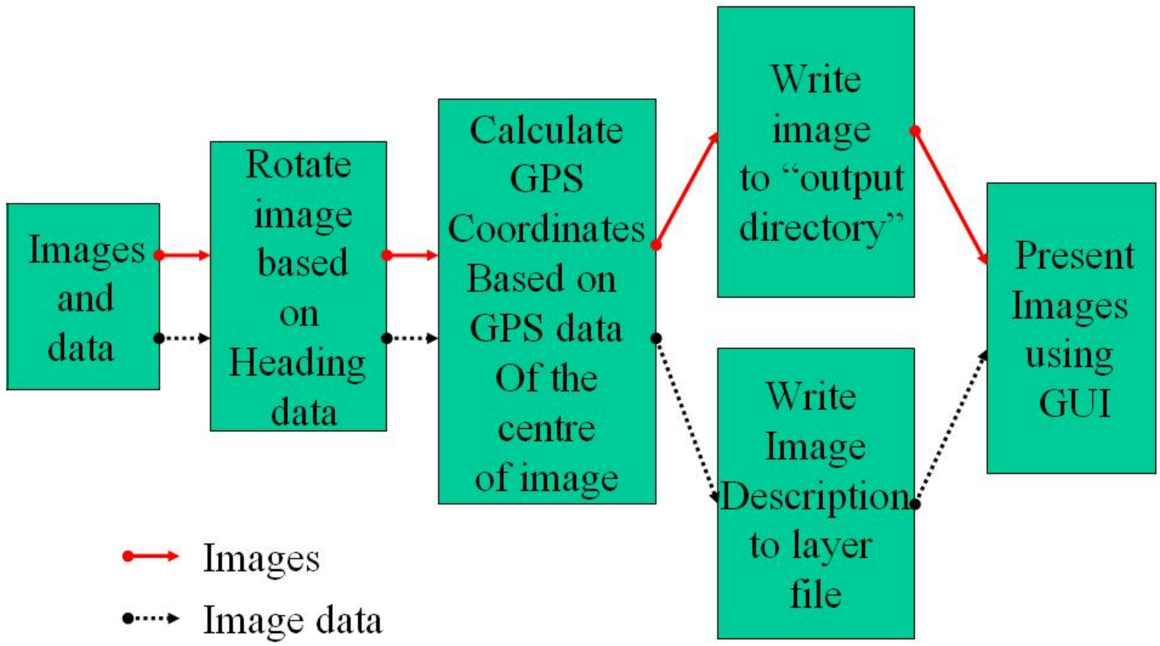

Figure 10 – Camera Stitching System Block Diagram

The Process is split into stages the Matlab optimization and processing stage and the customized "NASA World-wind" software image laying stage. The Matlab code collects data and images from the input directory and performs re-orientation on them to orient all images towards North. Based on the altitude information associated with the image, the code then stretches or compresses the image to a base or reference view altitude for all images. For the purpose of "NASA World-wind" software the Matlab code calculates the GPS co-ordinates of the corners of each image based on three factors, GPS co-ordinate of the centre of the image, altitude of the image and the field of view of the camera. Finally the Code creates an XML image description file for each image and places the images and their respective description files to the output directory. In order to implement a GUI, open source "NASA World-wind" was customized to give it a few additional features. The customized GUI collects the images and their corresponding data from the output directory and places the images relative to one another using positional data and overlays GPS grid lines on the final layout of images. Capabilities provided by the GUI include the ability to create customized world views using images taken from flight, similar to Google Earth, displaying positional and heading information of any point or object of interest to the user, flip through stacked similar images, ability to zoom, pan and tilt images, and ability to place markers as user desires. Figure 11 is a screen shot of the final representation of the images in the GUI; it also has an inset showing the initial look of the GUI before zooming in onto desired location

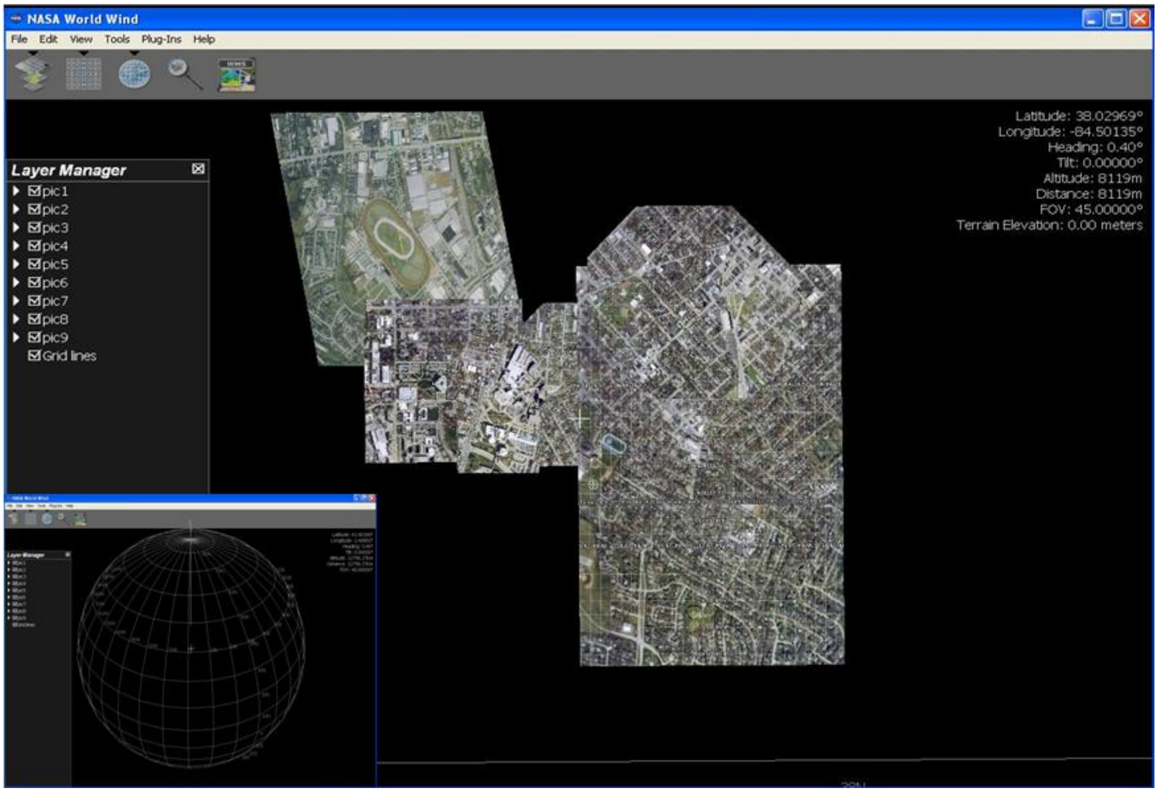

Figure 11 – Image Stitching Software GUI

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 12.

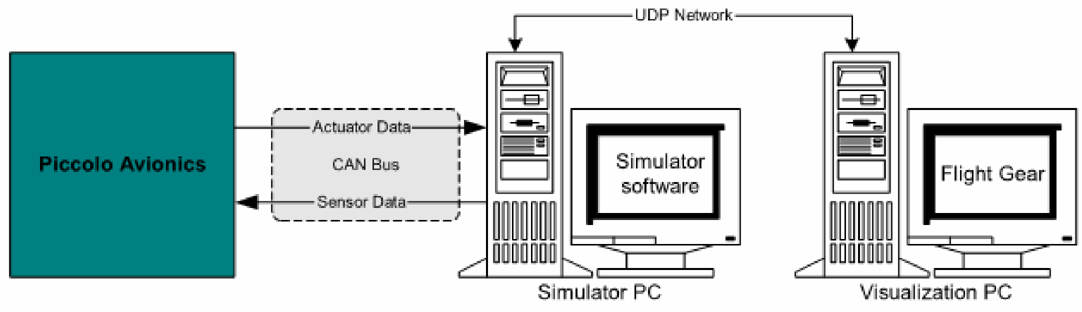

Figure 12 – Hardware in the loop simulation[3]

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 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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10 Appendix

2006 UK Southern Komfort (UKSK) Fact Sheet

The University of Kentucky unmanned aerial vehicle (UAV) system designed for the 4th 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 SIG-KADET SENIOR design with autonomous control, high-bandwidth communications and state-of-the-art image University of Kentucky. (**Contact information: James E. Lumpp, jel@engr.uky.edu, 859-257-3895**)

Aircraft Specifications:

- Wing: 6.7 ft span and 8.2 ft^2 wing area
- Empty Weight: 6.5 lbs
- Total Weight: ~12 lbs
- Propulsion: 1 0.61 Glow fuel engine with 12x6 (wooden) propeller
- Fuel Capacity and Type: 0.675 lbs of Glow fuel
- Flight Control System: Conventional 3 axis control pushrod system, steerable tricycle landing gear
- Autopilot: Cloud Cap Technologies Piccolo II
- Electrical Power: Rechargeable NiMH and Lithium-ion batteries
- Operating Frequencies: Telemetry and control: 902-928 MHz frequency hopped spread spectrum; video signal 427.25 MHz; RC: 72 MHz Band (Channel 45)
- Imaging System: 3 MP digital video and still camera transmitting real-time video and on-board storage of still images
- Custom Ground Imaging Software to generate composite map of target area
- Primary Construction: balsa, plywood and monokote airframe and wings