Phoenix III 2008 AUVSI UAS Team Journal

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Abstract

The University of West Florida (UWF) Unmanned Aircraft Systems (UAS) entry in the 2008 Association for Unmanned Vehicle Systems International (AUVSI) student competition was developed in response to the competition's mission objectives with the ultimate goal of meeting all required performance parameters. The 2008 entry utilizes the 2007 system as its base-line configuration with several key upgrades and improvements to the airframe, autopilot, vision system, ground station, network and RF link. The team, which was divided into two subgroups with specific responsibilities, used an objective driven approach to overcome limited resources. Subgroup A was responsible for airframe modifications, component installation and autopilot integration while subgroup B was responsible for the vision system, ground station, system network and RF link. The team's guiding principles were safety, robustness, and autonomy during all aspects of the design with the main goal to improve on the previous year's target acquisition and recognition capabilities and upgrade of all systems necessary for autonomous flight. To meet these goals, an advanced autopilot system was installed, an additional high resolution CCD camera for full motion video (FMV) was integrated, the existing high resolution still shot camera was improved by utilizing the camera's FTP push feature allowing for real-time image analysis, and monitors usable in direct sunlight were utilized on the ground station. Additionally, to overcome the poor quality FMV of the existing base-line vision system, an additional RF link dedicated to FMV transmissions was added. These system upgrades and improvements over the previous year's entry yield a more competitive platform.

1 Introduction

The use of autonomous UAS systems is on the verge of exploding on to the civilian and military industrial complex. Much of what has been seen to date has been rush-to-the-field prototypes. The Department of Defense and Homeland Security have plans to integrate

UAS vehicles into all aspects of their ISR (intelligence, surveillance, reconnaissance) operations — in some cases taking the ISR mission over completely. Currently, the United States has a technological edge in UAS development and operations. To maintain this edge, it is imperative that colleges and universities increase the flow of UAS experienced engineers into the marketplace. UWF is committed to supporting UAS research and development in its curriculum.

The UWF UAS team started the project for the 2008 AUVSI Student UAS Competition by identifying the key performance parameters and safety requirements based on the competition rules and objectives. These parameters and requirements were the guidelines used throughout the UAS design and development.

1.1 Key Performance Parameters

The team identified the following key performance parameters used for design and development:

- **Autonomy** — Autonomous flight and navigation of the UAS through GPS way-points with the ability to execute a search pattern;
- **Imagery** — Identification of all targets and their associated characteristics (i.e., shape, background color, orientation, alphanumeric and alphanumeric color);
- **Target Location** — Identification of the target location within 50 feet;
- **Mission Time** — Imagery, location and identification provided in real-time with the overall mission time under 20 minutes; and,
- **In-flight retasking** — Addition of GPS way-points and search area adjustment at anytime during the mission.

1.2 Safety Requirements

Safety is of the utmost concern in this project. Design requirements will meet safety specifications set forth by the Academy of Model Aeronautics (AMA) and the AUVSI. In accordance with AUVSI regulations, if the aircraft loses radio contact with the operator, it is programmed to automatically execute full right rudder and full right aileron in such a manner as to cause it to crash. This maneuver is required so that it will crash within close proximity to the operator for ease of visual location and to decrease the probability of harming individuals outside the flight safety zone. In addition, control of the aircraft must be remotely returnable to the operator at all times to ensure safe operation of the aircraft in case of an autopilot malfunction. A hardware switch, controlled by a RC servo, is used to toggle the aircraft from radio control mode to autonomous control. Due to the simplicity of this type of switching system, there is less liklihood of failure during a mission.

2 UAS Platform

The Phoenix III aircraft, shown in Figure 1, is loosely based on the Senior Telemaster design used for previous UWF UAS platforms [1] and is built primarily in a traditional fashion using materials such as balsa wood, light plywood, foam and some composites. These materials ensure that the aircraft remains light in weight but strong. The Phoenix III has many features that make the aircraft the perfect platform for a UAS. For example, a carbon fiber support tube spans 80% of the wing, and the cargo bays are large in size. This makes for a strong support structure for the wing of the aircraft with the ability to store the large amount of equipment that makes an autonomous UAS possible.

Figure 1. UWF UAS.

The original engine was upgraded from a 0.46 cubic inch engine to a 1.2 cubic inch engine and a larger fuel tank was installed (40 ounces versus 24 ounces) thus giving the UAS a loiter time of approximately 30 minutes. This loiter time length gives the team a greater chance of finding and identifying targets.

As a result of the larger fuselage, the horizontal and vertical stabilizer sections were strengthened and increased in size to fit the new airframe. In addition, reinforced bulkheads were incorporated in the cargo bay to protect the avionics modules. Furthermore, the autopilot was mounted in a safe box to protect it from high shock forces in the event of a crash. Also, to enhance modularity, junction boxes were built into the firewall separating the cargo bay from the airframe in order to facilitate replacement of servo controls and improve damage inspection access. To provide added protection against hard landings, the landing gear was reinforced with a fiberglass mesh.

2.1 Aircraft Layout

The current aircraft has undergone extensive modifications to house the new autopilot system and vision system as the previous layout of components was not sufficient for the current system. One shelf, which maximizes storage space while allowing maintenance tasks to be performed without much disassembly of components, houses the network switch, the autopilot safe box and the RC servo controlled throw switch for control between the autopilot and radio control. As shown in the upper left of Figure 2, an additional shelf was constructed to place the GPS away from all other components and as close as possible to the antenna to minimize any signal loss due to antenna cable length. To assure maximum visibility of the satellites that provide positioning data, the antenna is mounted under the canopy at the top of the aircraft and oriented so that it is parallel to the horizon.

The electrical bonding of the GPS antenna to the aircraft ground is extremely important. If this is not done properly, antenna performance characteristics can become distorted and nulls may appear in the antenna radiation pattern, which may cause erratic navigational readings or signal drop out. Due to the composite material of the UAS airframe, the antenna installation includes direct metal-to-metal contact of the antenna mounting hardware metal backing plate to an internal ground plane via solder.

The engine, a Thunder Tiger 120, is mounted to a Hyde vibration damping motor mount as shown in the bottom part of Figure 2. This mount is designed to reduce the amount of vibration transmitted to the airframe by 60%. This will allow for the on board components to be less affected by constant vibrations that occur during flight. To further damp vibrations, each component was mounted on a set of rubber o-rings. These precautions were taken to avoid malfunctions of previous designs that were caused by vibrations.

Finally, the torsional rigidity of the Phoenix III wings was increased through the use of modified carbon fiber tubes. In addition, a pitot tube was added to the port wing. The mounted pitot tube, which is shown in the upper right of Figure 2, will allow the autopilot to receive accurate UAS airspeed data.

Figure 2. UWF UAS showing GPS module, wing mounted pitot tube and motor vibration damper.

3 Systems

Several electronic components are pivotal to the operation of the UAS. The electronic and electromechanical sensors feed aircraft speed, orientation and altitude location as well as power supply status and GPS system fix mode to the autopilot. The following electronic modules are used in the UAS:

- Autopilot;
- Vision system;

- Embedded computer;
- Electrical power system;
- Communication link; and,
- Ground Control System (GCS).

Figure 3 provides a general block diagram description of the major components of the Phoenix III control system. The components included in the block diagram are briefly explained below.

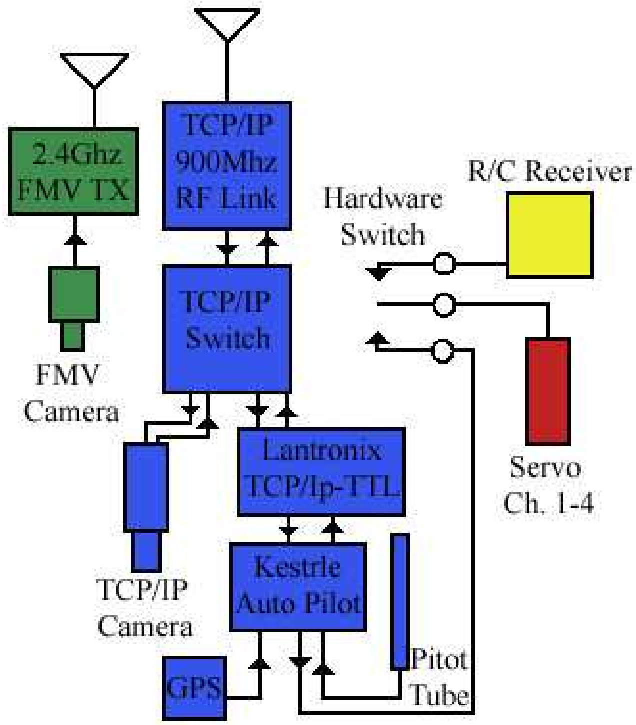

Figure 3. System block diagram.

3.1 Autopilot

The 2008 UWF UAS team decided early on that an off-the-shelf autopilot would be a necessary addition to the Phoenix III aircraft. A requirements matrix was developed to help the team identify necessary criteria to select the new system based on critical flight control aspects of the UAS. The team reviewed several off-the-shelf systems and selected the Procerus Technologies Kestrel autopilot system [2]. The Kestrel is an advanced, small, light weight unit that has excellent capabilities and can also be used for a UAS that is much smaller than the Phoenix III.

The Kestrel autopilot system consists of 4 major subsystems: the autopilot, the pitot tube system, the GPS and the Lantronix port redirector. The stock Kestrel configuration calls for a RS232 serial port connected to a wireless modem instead of a port redirector for communications to the ground station, but the Phoenix III uses a 1.53 Mb/s 900 MHz downlink for communications. This configuration was chosen due to the delay of manual controls and communication range of the modem recommended by the autopilot manufacture. Data is sent to the plane from the ground station through a network connection, and then is converted to a TTL level serial communication for the autopilot through the Lantronix port redirector. The autopilot is on a network with the rest of the components on the aircraft. The port redirector has proven to be a very efficient way to communicate with the autopilot system.

The autopilot has various integrated sensors that allow for autonomous flight. There are three axis rate gyros, three accelerometers and differential and absolute air pressure sensors to estimate the altitude and the airspeed of the aircraft during a mission. In addition, an external GPS, which uses a 3.3 VDC regulated supply from the autopilot, is used to determine position of the UAS. The particular GPS used is the Furuno GH-81 [3]. Finally, as noted earlier, the autopilot is mounted in a [Delrin] safe box to avoid excessive shock forces in the event of a crash. The Delrin box was modified to include two DB-25 connectors. These connectors allow for easy removal of the safe box without putting undue stress and strain on the autopilot circuit board.

3.2 Vision

Through practice flights and past competitions, many problems with the vision system were identified. The previous system consisted of a single still shot camera with the capability of live video output. The problem with this configuration is the limited bandwidth of the wireless system, which resulted in the ground station receiving poor quality live video. The current vision system is dedicated primarily to the identification of targets and their relative position. The system is composed of a forward looking, target anticipating live feed CCD camera as well as a high definition, high speed still shot camera. Due to the relatively high speed of the aircraft, this design gives the operator the advantage of preliminary target identification via FMV, setting up for a precision capture high definition (HD) image of the target as shown in Figure 4.

Figure 4. Image captured using UWF UAS IQeye 705 camera.

3.2.1 Video

To overcome the problem with bandwidth and target recognition, the live video system was isolated from the UAS network through the use of an off-the-shelf aerial video transmitter and receiver system. The 2.4 GHz Black Widow A/V diversity receiver [4] was chosen because it offers a superior signal quality video. The NTSC standard signal transmitted from the aircraft is analyzed at 100 Hz by a pair of sensitive receivers; the signal with the best signal to noise ratio is routed to the output of the diversity switch virtually assuring a drop-out free video. Furthermore, the switching between receivers is only performed between video frames to eliminate any switching noise from being seen on screen. On the aircraft, a Black Widow 2.4 GHz 1 W transmitter is used to transmit the video signal to the ground station. The antennas used to receive the FMV signal are two 8.5" 14 dBi circular polarized antennas with a 30° horizontal and vertical beam width. To increase the field of view, the antennas were offset 15° from the horizontal as seen in Figure 5.

Figure 5. Ground station receiver antennas.

3.2.2 Picture

The high resolution camera used on the Phoenix III is an IQeye 705 from IQInvision [5]. It offers a 5 megapixel resolution and runs an embedded Linux, which facilitates connection to the ground station and Single Board Computer (SBC) operating systems. The camera comes with an FTP push capability so image recording is seamless with the ground station. In addition, the camera can store up to 5000 pictures using internal memory.

3.3 Embedded Computer

The onboard image overlaying system is designed around the TS7260 SBC, a PC104 form factor computer [6]. This system is based on a 200 MHz ARM9 CPU with with 32 MB

SDRAM, 32 MB NAND flash, 2 USB 2.0 compatible interfaces, a 10/100 Ethernet port, 30 digital I/O lines and 3 standard COM ports The SBC computer was chosen due to its power efficiency (less than 0.5 W are consumed when the ethernet is disabled) as well as support for HTTP requests, which are used to update real time over-lay flight data on the high resolution camera.

3.4 Electrical Power System

The electrical power system is divided into two main subsystems; the voltage regulators and the battery packs. Lithium polymer batteries, which must be used with *extreme* caution [7], power all on board systems; one 14.8 VDC 4000 mAh battery powers the avionics while one 7.4 VDC 2100 mAh battery powers the RC servos. The avionics modules have on-board switching regulators while the Black Widow transmitter and FMV camera require the use of an external 12 VDC regulator. Based on component current consumption calculations, the avionics battery will discharge to unsafe levels before the RC servo battery, but it will provide power for approximately 6 hours.

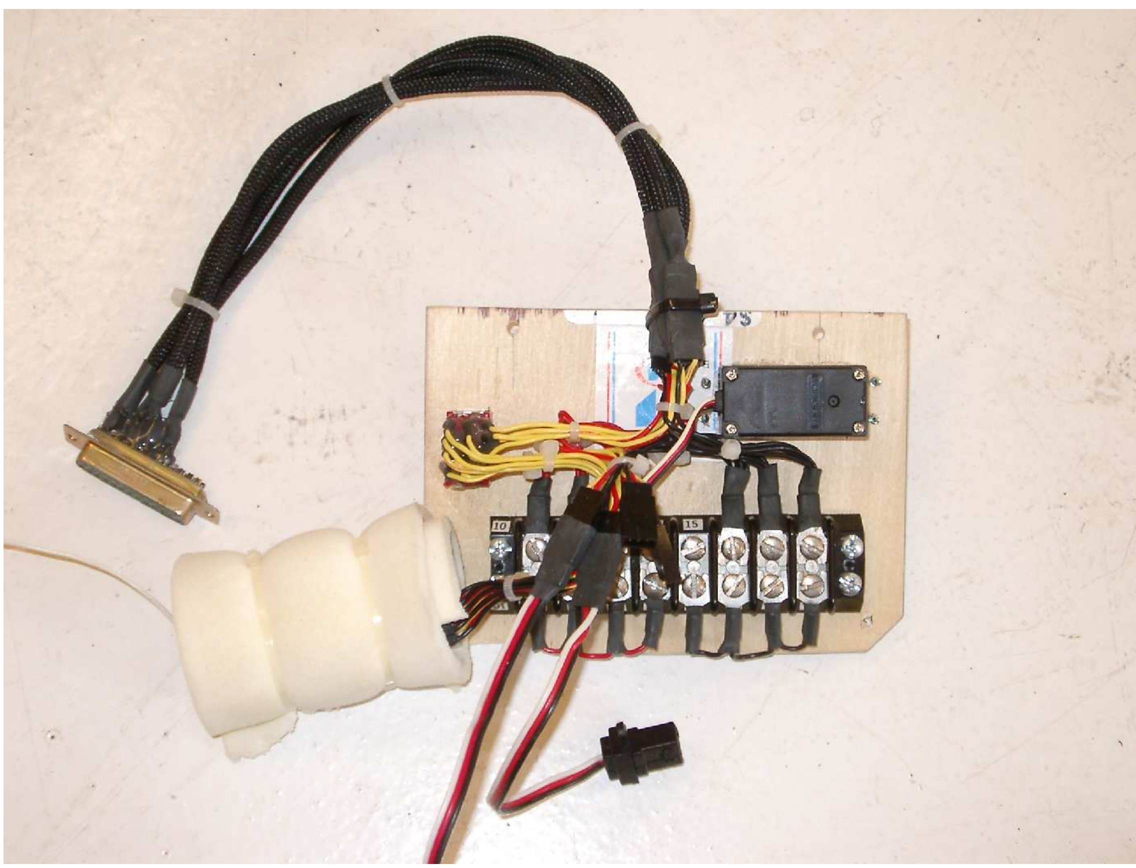

Figure 6. Electrical power distribution module.

3.5 Communication Link

The communication link between the aircraft and the ground station is maintained by the use of a RF radio implemented by a bridge [8]. The RF network bridge makes it possible to send network data from the autopilot, which contains telemetry information that is displayed via Graphical User Interface (GUI) software, as well as video from the network camera to the computer on the ground.

The specifications for the RF bridge are as follows:

- RF transmission rate: 1.536 Mb/s;
- Ethernet throughput: 935 kb/s;
- Output power: +21 dBm (4 W EIRP with a 15 dBi antenna);
- Receiver sensitivity: 97 dBm at 10^4 BER (112 dBm with a 15 dBi antenna);
- Radio link budget: 148 dB with a 15 dBi antenna;
- Range: 50 miles line of sight (LOS) with a 15 dBi antenna;
- Radio channels/bandwidth: 12 non-overlapping with 2.083 MHz spacing and 1.75 MHz occupied bandwidth;
- Automatic frequency select: radio channel is automatically selected and adaptively optimized;
- Error correction technique: sub-block error detection and retransmission; and,
- Adjacent band rejection: surface acoustic wave (SAW) receiver filter attenuates cellular and pager interference.

3.6 Ground Control Station

The ground control station (GCS) is comprised of the following major subsystems:

- RF link;
- Displays (for FMV, virtual cockpit and image analysis);
- Network switch;

- User interface; and,
- Ground station power system.

These are described in more detail in what follows.

3.6.1 RF Link

The RF link is split into two subcomponents: FMV and UAS data link. The antennas are mounted on a transmitter/receiver array, which consists of two circular polarized 14 dBi antennas for FMV and one 15 dBi directional antenna for telemetry data.

3.6.2 Displays

Previously used GCS video monitors were replaced with two Avalex 9 flat panel monitors [9]. Avalex monitors are used extensively in military and civilian markets and were selected due to their high quality displays and their ability to operate effectively in a high-level of sunlight. The monitors, which are used for the FMV and virtual cockpit computer, have front mounted, back-lighted bezel buttons allowing the operator to switch between video input sources as well as control the display brightness. Additionally, a video Loop-thru connector is available to provide video output of the selected video for viewing on another display or for recording.

3.6.3 Network Switch

The ground station network switch is used to connect the virtual cockpit computer and image analysis computer to the data communication link.

3.6.4 User Interface

The GCS virtual cockpit GUI software, which is shown in Figure 7, is supplied by Procerus Technologies for the Kestrel autopilot. The main purpose of the ground control monitoring display is to show the aircraft telemetry data and allow changing of the desired way points while the aircraft is in flight. The information collected from onboard sensors is passed to the program serially over the RF network bridge and is parsed for display. The user interface also includes a Futaba RC transmitter [10], which is used for manually controlled take offs and landings.

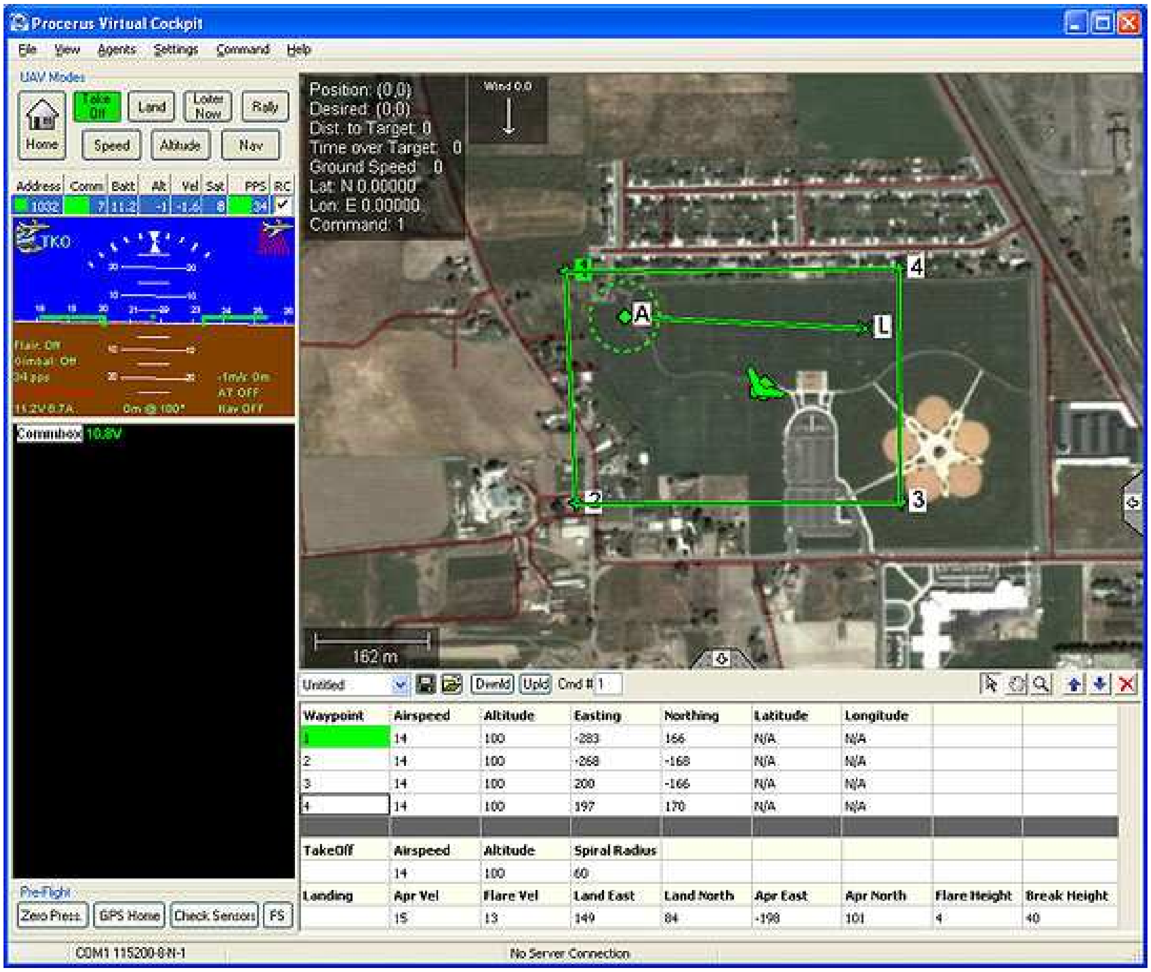

Figure 7. Virtual cockpit GUI.

3.6.5 Ground Station Power System

The ground station power system is provided by a primary power system and a back up power system. The primary power system is made up of an AC bus and a DC bus. The AC bus is obtained from a 5550 W gasoline powered portable generator, which provides 2-20 A 120 VAC outputs and 1-30 A 120/240 VAC output. Fully fueled, the generator provides 8 hours of operation. The DC bus is provided by 2 GW GPC-3060D power supplies that provide $0 - 30$ VDC at a maximum current of 2 A. The back up power system is provided by two car batteries with associated AC inverters.

4 UAS Testing

UAS testing was accomplished in a three phase approach during design and development. The first phase was at the individual component level and was completed in the lab. This phase tested all systems for proper operation and service ability prior to integrating them onto the platform. The second phase was completed with all components installed on the platform and consisted of mounting the UAS to a motorized vehicle and driving it through GPS waypoints in order to verify autonomous functions of the autopilot. Additionally, the aircraft was parked in a static position in order to test the ground station to platform operation. This consisted of ensuring FMV quality, autopilot telemetry, FTP operation, operational check of the manual flight control system and loss of communication failure mode. The final phase was flight testing. This consisted of numerous flights where rudimentary control of the UAS flight handling characteristics was verified. The follow on flight testing expanded the flight envelope to include autonomous flight, in flight re-tasking, vision system performance, and failsafe operation.

5 Innovative Features

The 2008 system utilizes the 2007 system as its base-line with several key improvements. These improvements resulted from the problems encountered during the previous competitions. The self imposed design and development mandate was to improve the overall target recognition and display capabilities of the UAS. Additionally, the team was able to achieve key innovations in several areas as described below.

Problem: Poor quality FMV.
Solution: The poor quality FMV was caused by the bandwidth limitations of the RF link. The base line platform had one RF link that was used to transmit video and vehicle telemetry. The current system adds a dedicated RF link for FMV, which frees up the second link for vehicle telemetry.

Problem: Aircraft vibration interfered with still shot capture.
Solution: During the 2007 competition, it was observed that with the UAS engine running, images captured were unrecognizable. This was caused by aircraft vibration transmitted to the camera mount. Vibrations were mitigated by installing a new engine mount that provides 60% vibration dampening. Additionally, the camera is now mounted on rubber shock mounts.

Problem: Target recognition window limitation.
Solution: The previous system had only one camera oriented perpendicular to the airframe (i.e., looking straight down). This system had several target recognition limiting factors. Early target recognition was impossible due to the aircraft velocity and limited field of view. The improved system adds a forward looking FMV camera used for early target recognition. The original camera is now used for target capture and is queued by the operator.

Problem: Operator interface degradation.
Solution: The operator's ability to identify targets was impeded due to the physical size of the monitor and poor readability in bright conditions. The improvement for this year adds two monitors, which provide double the image size and are designed to operate in extremely bright conditions.

Problem: Image analysis affected flight time duration.
Solution: The 2007 mission profile consisted of capturing images in flight and storing them on the camera's memory card. Then, when the UAS landed, the team hurriedly download the images for post processing. This caused the previous team to limit flight time to allow for post flight image processing. The new system uses a seamless approach as it is able to process images in real time during the mission using the existing FTP push software on the still shot camera and the addition of a FTP server on the ground station.

Problem: New autopilot communication box limitations.
Solution: Due to the problems associated with the addition of another 900 MHz antenna, a Lantronix port redirector is used. The redirector allows the information to be sent to the autopilot using the existing RF link. The data is sent to the UAS through the network on the plane which is converted to TTL level serial communication for the autopilot.

Problem: Heat build up due to the autopilot.
Solution: Due to the heat that is generated by the Kestrel autopilot processor, the team added two pressure taps on the aircraft. The two pressure taps are run from the autopilot safe box to the outside of the plane. Using surgical rubber tubing, the UAS will use the air moving past the tube to create a negative air pressure. This will pull the hot air out of the autopilot box creating airflow over the surface of the autopilot processor chip.

6 Conclusions

The UWF UAS team's design process for the 2008 AUVSI Student UAS competition entry followed an objective driven, phased systems integration approach. Each of the six major subsystems (airframe, autopilot, vision system, ground station, network and RF link) were fully tested and integrated and incorporated modifications and key enhancements to alleviate problems associated with previous UWF UAS designs. The completed UAS meets each performance parameters and satisfies all mandatory competition requirements.

References

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