An Experimental UAV System for Search and Rescue Challenge

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INTRODUCTION

Unmanned aerial vehicles (UAVs) implement technologies spanning aeronautics, robotic, electronic hardware, software, and sensing areas. Pilotless aircraft have been investigated from early in the development of flight, but recently their sophistication and capabilities have greatly expanded. In particular, advances in technology have made autonomous and semiautonomous robots possible [1]. UAVs with intelligent capabilities range from large-scale aircraft to microrobots. UAVs have become a common technology for armed forces with battlefield usage, including reconnaissance, target identification, and weapons delivery. UAVs for civilian applications are increasing as well for diverse tasks such as environmental monitoring, wildlife population tracking, wildfire monitoring, border patrol, and search and rescue. The importance of UAV technology is reflected in the efforts to create safety protocols and requirements for UAV manufacturers and operators [2].

Small UAVs offer important benefits for users. The robots can be deployed without the need for extensive airstrip requirements for takeoff and landing. Operating costs are typically low, and mission endurance may be high. For example, the benefits of small UAVs may improve the response time and coverage for search and rescue operations as opposed to that provided by conventional manned aircraft. The development of these small systems exploits the miniaturization of electronics and sensors [cf. 3], [cf. 4].

The UAV Challenge–Outback Rescue is an annual international competition for students, hobbyists, and filmmakers to promote the use and development of UAV technology. The lead sponsor is the Australian Research Centre for Aerospace Automation, and the competition is held in Queensland, Australia. The UAV search and rescue mission requires autonomous takeoff, flight, and landing with associated image processing and control needed to identify a mannequin placed in the Australian Outback and deliver an emergency medical package to this missing "hiker" [5].

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This work describes the UAV developed by the Missouri University of Science and Technology (S&T; formerly the University of Missouri–Rolla) Aerospace and Electronic Systems Society (AESS) student chapter for the 2008 UAV Challenge–Outback Rescue. This robot consists of a standard hobby remote-control airframe that is modified for autonomous flight, GPS-based navigation, ground image acquisition, and payload delivery. Off-the-shelf systems are integrated to provide capability for the search and rescue mission in a low-cost platform. The overall systems architecture and systems considerations are described. The development models a design and systems integration experience for students.

MISSOURI S&T UAV SYSTEM OVERVIEW

COMPETITION OVERVIEW

The annual UAV Challenge competition promotes innovation in UAV design and application. The competition specifies a search and rescue mission for an autonomous UAV that will takeoff, fly 1 nautical mile via defined waypoints to the search area, search a defined grid of approximately 3 km by 4 km, identify the location of a target mannequin (Outback Joe), drop a bottle of water near the target, return to the airfield, and land. The flight time limit is 1 hour. Competition criteria relate to the ability to perform these tasks autonomously and to document the development and testing process. The vehicles are limited by weight to 100 kg for rotary solutions and 150 kg for fixed wing solutions.

The telemetry, control, and monitoring of a UAV are provided by a ground station, where commands are given, vid-

eo and aerial data are relayed, and operator override is possible. A typical ground station provides a simple intuitive user interface allowing the operator to enter waypoints on a map and then initiate the UAV to fly the designated path and grid search. The UAVs are subject to tight safety requirements, and the ground stations must have a reliable data link with the UAV. In the 2008 course, the greatest distance from the ground station to the farthest corner of the search grid was approximately 7 km (4.5 mi).

A successful UAV project combines expertise in aerospace, electrical, and software engineering with interdisciplinary management and is an excellent design experience for university engineering students.

The competition rules are flexible regarding custom component development and off-the-shelf component integration. A student team has a wide range of design and emphasis options. The Missouri S&T UAV team chose a fixed-wing option for the vehicle and chose to emphasize system integration solutions [6].

AIRFRAME SELECTION

The UAV development started with an "almost-ready-to-fly" remote control hobby airframe. The selection of a specific airframe used criteria of reasonable cost, a large payload capacity for the electronics and the water bottle cargo, and a continuous flight time of at least 1 hour. Furthermore, the airframe needed stable flight characteristics and slow-flying capability to assist with autonomous reactions and image acquisition during flight. The airframe then placed constraints on the size and weight of the remaining onboard systems for autonomous flight, GPS-based navigation, ground image acquisition, and payload delivery. Two airframes with stable flight characteristics were investigated. The first vehicle was a SIG Kadet Senior (SIG Mfg. Co., Inc., Montezuma, IA), and the second was a Senior Telemaster (Hobby Lobby, Brentwood, TN). The Senior Telemaster is shown in Figure 1.

Figure 1.
The Telemaster airframe in the flight-ready configuration.

The SIG Kadet Senior is a popular "almost-ready-to-fly" remote control aircraft. As manufactured with balsa and plywood inner structures, the covered airframe without the engine weighs 2.95 kg (104 oz). The 164.5-cm (64.75-in.) fuselage also has plenty of space for the electronics and camera. A camera can be installed with an unimpeded view from the bottom of the fuselage. The extra-large payload of electronics, batteries, camera, water bottle, and fuel required a larger custom wing with greater lift and strength.

Senior Telemaster is another popular "almost-ready-to-fly" aircraft. The covered balsa and plywood airframe without engine weighs 4.76 kg (168 oz). The 160-cm (63-in.) fuselage also has adequate payload space, and it did not have internal bulkheads to complicate component placement. The unmodified stock wing of 8580 cm^2 (1330 $in.^2$) was successfully used for the UAV conversion. This airframe required a larger four-stroke glow fuel engine than the SIG Kadet Senior, but it could still takeoff on a 46-m (150-ft) grass runway fully loaded. The Telemaster was the airframe used for the 2008 competition.

SYSTEMS TRADE-OFFS

The systems were implemented based on component expense and the physical limitations of available space and load capacity and the associated issues of electrical power and processing needs. The fuel quantity for 1 hour of flight time and the water bottle cargo were set requirements. A

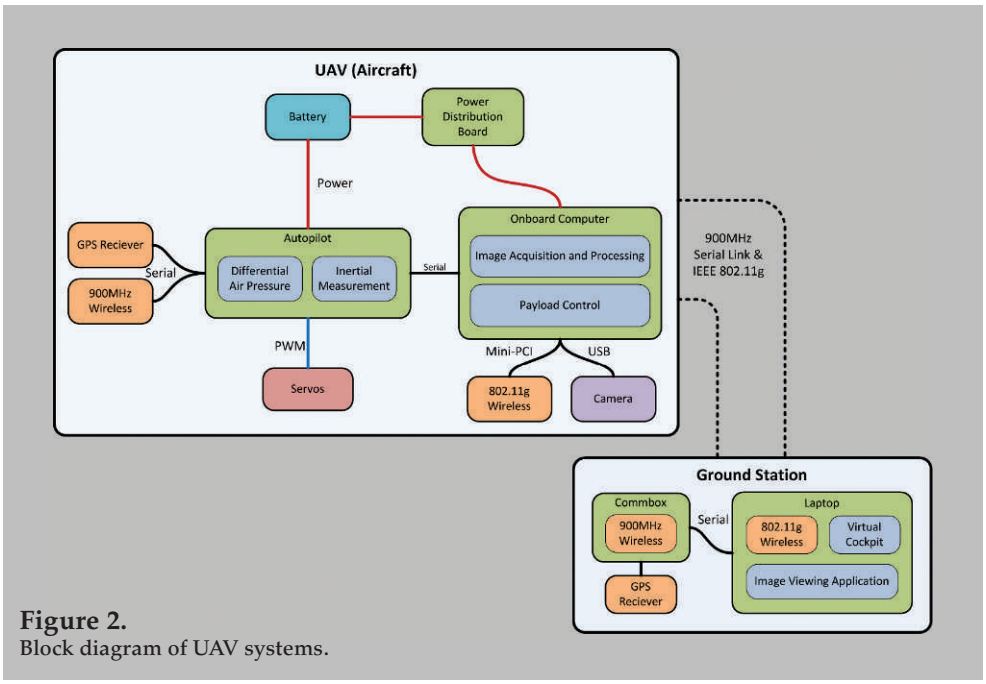

Figure 2.
Block diagram of UAV systems.

major design choice was how to implement the image processing functions for identifying pseudo-hiker Outback Joe. For the image processing to be performed by the onboard computer, the onboard computing capabilities would need to be more extensive, and a processing algorithm tailored to the application. For the image processing to be performed at the ground station, a robust high bandwidth (ideally five or more megabits) and long-range (five or more miles) wireless connection would be required. The systems were designed to handle the former option of onboard processing. However, the development time was insufficient for the 2008 competition, and a limited ground station approach was implemented. Future work is planned for enhancing the UAV with regard to onboard processing.

SYSTEMS APPROACH

A block diagram of the major systems and interconnections are shown in Figure 2. The main functions are

- avionics for the autopilot and manual override,
- GPS navigation,
- communications link,
- onboard computing,
- power and electrical distribution,
- onboard camera,
- payload delivery, and
- ground station instrumentation.

Key systems include the autopilot, the onboard computer, the power distribution system, imaging software, and payload delivery system.

An important safety function is for flight termination in the event of some failure, especially communication link failure. The autopilot may be configured with multiple safety options. If the failure is not related to communications, the ground pilot may take immediate manual control through the 900-MHz serial link. After a preset time without communication to the ground station, the autopilot may fly to a designated rally point and then follow a designed path back to home. By flying to a rally point located at the center of the corridor to the search grid, the autopilot can stay within the mission boundary on its way home as opposed to taking a straight path home that could possibly go outside the boundary. A second time preset may force an immediate landing in which flight control surfaces are adjusted for a minimum-energy landing. Alternately, once the UAV is within the range of the separate line-of-sight (LOS) radio control (RC) radio system, the ground pilot may bypass the autopilot to manually fly and safely land the airplane using standard RC radio equipment. The 72-MHz radio system may directly control flight servos. Note that the servo multiplexer relies solely on digital logic chips, meaning no software is involved in the switching of the servo control from the autopilot to the RC receiver (this design reduces the risk of software glitches/failures).

DESCRIPTION OF KEY SYSTEMS

AUTOPILOT WITH GPS RECEIVER

The Kestrel autopilot manufactured by Procerus Technologies (Orem, UT) was selected. The Kestrel is light weight at 16.65 g and tightly integrated with dimensions 5.08 cm × 3.48 cm × 1.19 cm. This system uses three microelectromechanical systems (MEMS) accelerometers and three MEMS gyroscopes to provide a six degrees of freedom inertial measurement. Other features are differential air pressure sensors for altitude and air speed measurement, a two-axis magnetometer (for dead reckoning), and an external GPS receiver for guidance and navigation.

Communication between the autopilot and ground station is provided by a 900-MHz Maxstream XTend serial modem (not shown in Figure 2) and a ground station 19-dBi Yagi-Uda directional antenna. The listed range of up to 60 km (40 mi) LOS, with a listed power output of up to 1 W, exceeded the maximum distance in the competition of 7 km (4.5 mi). This communications link is used to upload way-

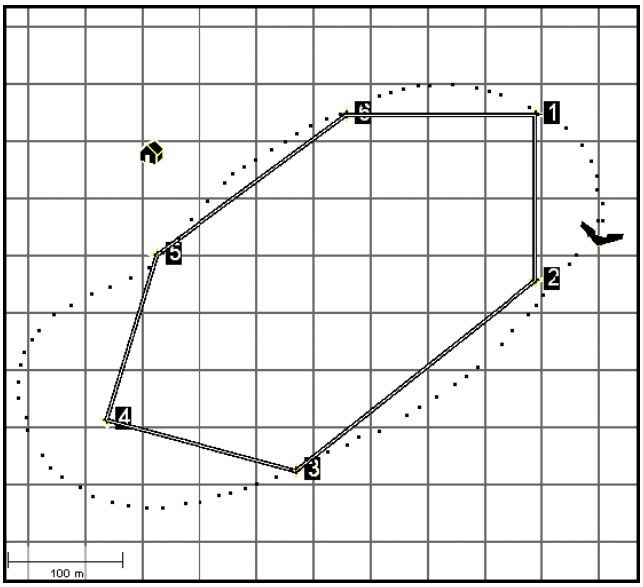

Figure 3.
Example navigation through GPS waypoints during autopilot tuning.

points and monitor aircraft telemetry, whether in flight or on the ground. Also, the radios selected provide an 115 200 b/s 256-b AES-encrypted link to ensure secure communications between the UAV and the ground station at all times.

The autopilot integration and control loop tuning followed the manufacturer's recommended procedures. The associated virtual cockpit software for the ground station logs and displays live telemetry, including GPS location, flight data (airspeed, pitch, roll, and yaw), battery voltage, and distribution current. Flight performance during autopilot tuning is illustrated in Figure 3. Details are given in prior literature [7].

ONBOARD COMPUTER

The JRex-PM disk-size SBC (Single Board Computer) computer manufactured by Kontron (Poway, California) was selected to provide capability for all onboard functions, including possible imaging processing. The main board has dimensions of 147 mm × 102 mm. The board requires a 5-V power supply and features power consumption of less than 50 W (typically 35 W). It has with a 1.8-GHz Intel Pentium M processor, 1 GB of DDR-RAM, and a compact flash memory slot. A 4-GB compact flash card that was loaded with Ubuntu Linux Server provided software. This operating system was chosen to minimize overhead.

The computer interconnections are shown in Figure 2. These include the Kestrel autopilot, the camera, the payload relay, and a Mini-PCI IEEE 802.11 g/b wireless card for ground station communication. An additional image and a data storage Universal Serial Bus (USB) flash drive are incorporated.

POWER DISTRIBUTION SYSTEM

A custom four-layer PCB was designed for power distribution to all components. The circuit board is shown in Figure 4. The

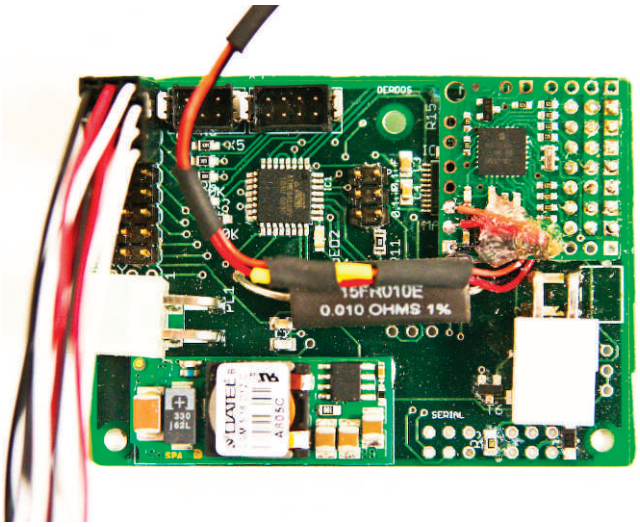

Figure 4.
UAV power distribution circuit board.

system is based around two 11.1-V, 3200-mAh lithium-polymer battery packs (totaling 71 Wh). The power distribution regulates the power from the batteries with the use of a 5-V DC/DC Converter from Murata Power Solutions (Mansfield, MA) (LSM-5/16-D12-C) that is capable of supplying 16 A of continuous current with an efficiency of 95%.

This power distribution board has several functions other than supplying power to all of the servos, the onboard computer, the autopilot, and the camera. It measures the total current draw from the batteries. Also, it facilitates a servo expansion board for future configuration flexibility that connects to the autopilot (Figure 4 upper right corner of PCB). An Atmel (San Jose, CA) ATMega168 microcontroller is included on the power distribution board to allow additional functionality regarding servo control and battery monitoring.

IMAGE ACQUISITION AND PROCESSING

A Canon A640 camera (Cannon U.S.A., Inc., Lake Success, NY) was selected due to its capability for the onboard computer to control image capture and to transfer those images to the onboard USB flash memory. The camera offered processing simplicity using USB through Picture Transfer Protocol and the gPhoto2 library. Also, the 10-megapixel images provided a calculated 3-cm resolution at a cruising altitude of 122 m (400 ft). Power was supplied from the UAV's 5-V supply, eliminating the need and weight of the standard camera batteries. The image acquisition rate was limited in that too high a rate would power down the camera with no means to turn the camera back on with software. One image every 3 seconds was adequate to prevent this error, while still covering the search area in a reasonable time. The competition required a 12-km^2 area to be searched in less than 1 hour. This constraint along with the camera resolution set the needed altitude of 400 ft or greater and speeds of 18 m/s (40 mph) or higher.

IMAGING SOFTWARE

The initial plan was to process the images onboard using image recognition and computational intelligence algorithms. Due to the limited development time and resources available to the team before the competition, a simpler, less-autonomous approach was adopted. First, the onboard computer captured regular images, tagged with latitude, longitude, altitude, velocity, and heading, and stored the images using the EXIF standard. Second, the server software relayed the stored images back to the ground station when the WiFi connection was available. The 802.11g standard would allow the high bandwidth necessary for large images, but it could not guarantee the range, and communication was lost frequently. Finally, the operator at the ground station manual scanned for the target. This limited approach must be changed in future implementations.

The client software has two main modules: the data client and the image viewer. The data client maintains the connection with the server and is built around the assumption that communication conditions will be poor. Whenever connection is lost, it continuously attempts to reconnect, and when connected, it downloads all of the pictures from the server, which are not present locally. The image viewer loads the image along with the associated EXIF tags that contain location and orientation data and then displays them in an intuitive interface that allows for fast processing by the operator. Figure 5 shows an example image.

PAYLOAD AND PAYLOAD DELIVERY

The payload, as required by the rules of the competition, consists of a water bottle containing 500 mL of water. The water bottle is made from high-strength polycarbonate, and it is enclosed in a high-density foam capsule. A small parachute is attached to the bottle to slow the descent such that the bottle will survive an impact from 120 m (400 ft).

The foam capsule enclosing the water bottle is equipped with a lightweight steel tab that is held by a servo inside the fuselage. When triggered, the servo pulls a pin from the tab and releases the bottle. The consistency and accuracy of the water bottle delivery system has been verified through testing. Even with a parachute attached, the payload can be delivered in reasonable wind with relatively high accuracy (±20 m).

TECHNICAL DISCUSSION

AIRFRAME ISSUES

Based on extensive experience with both the SIG Kadet Senior and the Senior Telemaster, the Telemaster was a better platform for the mission. It has a very spacious interior with fewer bulkheads than the SIG Kadet Senior, allowing components to be placed more conveniently. However, it did also have its own drawbacks, primarily its performance as a "tail-dragger," (Figure 1) that makes takeoff and landing more challenging. A custom wing design for the Telemaster may significantly improve takeoff and landing performance (through the use of flaps) as well as allow for higher cruise speeds from a more efficient airfoil. Structural reinforcements may also aid in coping with the large payload.

SYSTEMS ISSUES

The constraints of weight, size, power requirements, and cost influence the selection of the various subsystems. More experience with UAV and the development of a specific image processing solution will perhaps allow more optimal selection of components.

In particular, the 802.11g wireless link was inadequate for the mission. Even with a high-gain antenna, the connection was frequently dropped or bandwidth was limited for distances as short as a kilometer. Even for an onboard imaging processing solution, communication needs higher reliability. Other hardware choices as well as mesh protocol (as opposed to the TCP protocol) may improve performance. By contrast, the 900-MHz serial link provided dependable, albeit low-bandwidth communication between the autopilot and ground station.

IMAGING METHODOLOGY

A truly autonomous imaging solution is desired because the main purpose of a search and rescue UAV is not to collect images but to locate a specific target efficiently. Onboard processing would reduce the demands on the link, base station, and operator and would allow multiple UAVs to operate simultaneously with a single base station. Also, onboard processing would provide immediate processing of images without transmission delays. For general aerial imaging or mapping, onboard processing would facilitate the collection of high-interest images. Possible approaches include the initial plan to provide dedicated, intelligent onboard processing for image target recognition and a hybrid plan in which significant preprocessing is performed onboard and tailored data sets are sent to the ground station for more flexible target recognition procedures. Trade-offs are present with regard to onboard computational power and speed, communication link capacity and reliability, etc. However, both approaches require a better high-bandwidth communication link.

EDUCATION

The UAV competition was the main activity for the IEEE AESS student chapter. It attracted students from electrical, computer, and aerospace engineering departments. In addition to the administrative officers, a chief engineer position was created to manage the UAV project. Technical responsibilities were given to project directors in the areas of 1) airframe and propulsion, 2) avionic systems, 3) image process-

Figure 5.
Example image.

ing and target recognition, and 4) field testing and piloting. Faculty and industry advisors were associate chapter members. Some of the members used aspects of the design for undergraduate research projects.

CONCLUSIONS

The overall UAV approach discussed in this article provided satisfactory performance for the avionics systems; however, the design is limited with regard to the wireless link and the image processing. Future development will focus on redesign of the airframe platform, the wireless link, and the image processing. UAV flight characteristics need to be better understood and more thoroughly tested to accommodate less-than-ideal flight conditions. Full analyses of the link margin for spectrum management and of risk assessment to handle flight failure/termination events, e.g., loss of data link, GPS, or autopilot, are needed. Overall, the design experience demonstrated systems trade-offs present in a practical vehicle and UAV capabilities even using off-the-shelf component integration. The prototype UAV could be used for aerial mapping, environmental monitoring, and search and rescue at a cost significantly lower than using traditional full-size aircraft for the same missions.

The Missouri S&T chapter participated in the 2008 UAV Challenge–Outback Rescue. The UAV successfully completed the practice, qualification, and tuning flights. Wind conditions caused a crash during the competition flight, but the performance was adequate for a second-place finish. The search and rescue challenge is difficult technically; no team from the 2007–2012 competitions has completed the entire mission to win the grand prize.

The current Missouri S&T chapter is designing avionics to upgrade a custom airframe that was developed in collaboration with a two-semester, senior design sequence in aerospace engineering [8]. The aerospace engineering students developed a radio-controlled vehicle that has stable flight performance and sufficient payload capacity. The technical focus of the current technical team is to investigate onboard image processing for more intelligent, autonomous operation for the search and rescue mission.

UAV projects are excellent design experiences for university engineering students. Major subsystems are the airframe, avionics, autopilot and GPS-based navigation, image acquisition, and processing. Students must deal with these component technologies as well as systems integration and operation challenges. Crashes occurred due to failure of a wing (overload) and autopilot communications link as well as rough wind. A successful project will combine expertise in aerospace, electrical, and software engineering with interdisciplinary management. ◈

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REFERENCES

[1] How, J. P., Fraser, C., Kulling, K. C., Bertucelli, L. F., Troupet, O., Brunet, L., Bachrach, A., and Roy, N. Increasing autonomy of UAVs. *IEEE Robotics and Automation Magazine*, Vol. 16, 2 (Jun. 2009), 43–51.

[2] Loh, R., Bian, Y., and Roe, T. UAVs in civil airspace: safety requirement. *IEEE Aerospace and Electronic Systems Magazine*, Vol. 24, 1 (Jan. 2009), 5–17.

[3] Jang, J. S., and Liccardo, D. Small UAV automation using MEMS. *IEEE Aerospace and Electronic Systems Magazine*, Vol. 22, 5 (May 2007), 30–34.

[4] Iscold, P., Pereira, G. A. S., and Torres, L. A. B. Development of a hand-launched small UAV for ground reconnaissance. *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 46, 1 (Jan. 2010), 335–348.

[5] Australian Research Centre for Aerospace Automation (ARC-SS). UAV Challenge (2012), http://www.uavoutbackchallenge.com.au, last access Jan. 23, 2013.

[6] IEEE AESS UAV Team. AESS UAV Team, Missouri University of Science and Technology (2012), http://www.aessuav.org/, last access Jan. 23, 2013.

[7] Erdos, D., and Watkins, S. E. UAV autopilot integration and testing. In *Proceedings of the IEEE Region V Technical Conference*, Kansas City, MO, Apr. 2008.

[8] Macke Jr., D. C., Watkins, S. E., and Rehmeier, T. Creative interdisciplinary UAV design. *IEEE Potentials*, in press.