Rose-Hulman Institute of Technology's Autonomous Helicopter for the 2001 Aerial Robotics Competition

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Introduction

This year, the Rose-Hulman Aerial Robotics Team has focused on building a versatile autonomous platform capable of meeting the core challenges of the 2001 AUVS International Aerial Robotics Competition (IARC). Modifications since the 2000 IARC event have focused on computer hardware and software. The former 133 MHz Pentium computer was replaced by a new Little-Board-style computer operating at 266 MHz. The new computer has many integrated capabilities that open new possibilities for onboard processing. Having made a transition to a new, more capable onboard computer, the team decided to invest time in switching from DOS to a more capable operating system. Having explored various operating systems, Linux has been found to provide the multi-tasking and connectivity capabilities that were not present under the former DOS environment. Communication by wireless modem has been replaced by a Cisco Ethernet system for higher bandwidth and increased operating range. Finally, development work has begun on a ground vehicle, which is to be carried by the helicopter and launched into the building to retrieve images of the target object.

Competitive Strategy

The AUVS 2001 International Aerial Robotics Competition requires an autonomous vehicle to interact with its environment by surveying a remote hostile area and returning useful information. This information, in the form of relayed images, will aid a technical research or rescue mission by allowing remote sites to be observed without risking human life. At this competition, the first goal is to demonstrate fully autonomous computer control of the helicopter. The second goal is to traverse the 3-kilometer range to the target site so as to demonstrate the long-range capabilities of the design.

The new objectives of the 2001 Aerial Robotics Competition raise many new challenges for a remotely operating system and push the capabilities of commercially available technology. It is especially the long-range aspect of the competition that pushes the limit of the design from prior competitions. Regular transfer of differential GPS correction logs from the ground to the vehicle is required to maintain good GPS solution. Communication from the vehicle to the ground in order to relay images is vital. Also, at long ranges when the vehicle's status is not directly observable, the team must rely on the telemetry system to provide information on the vehicle's orientation and operating status. Thus, a reliable and capable means of long-range communication of both control and image information is central to the new objectives.

After field-testing last year's communication equipment, the team decided that the radio modems and analog video transmitter would not reliably span the three kilometer distance. With analog transmission of image data, the image quality tended to degrade noticeably with distance. In addition, the radio modem connection became slow and unreliable. The team decided that the best way to ensure a clear picture from several kilometers away would be to digitize the image at the vehicle and transmit the pictures over a digital link. Using this method the image quality is independent of distance.

The team's strategy for overcoming the communications challenge was to replace the analog video transmitter and radio modem with a single 11 Mbps wireless ethernet connection. The consolidation of the communication systems has inherent benefits in that there are fewer devices to be powered and a potential source of EMI has been eliminated. With wireless ethernet, the standard maximum power for commercial units is 100 milliwatts. While this is good for battery life, the range for these units is typically designed for 800 feet outside. To get the wireless ethernet system to run the full three kilometers, a high-gain directional antenna on a tall pole will be used on the ground station to communicate to the aerial vehicle. Depending on the terrain, an aerial subvehicle carrying a wireless bridge may be necessary to serve as a relay station. Wireless ethernet's ability to relay signals between catchment zones means that communication distance can be expanded.

Along with a change in our communication system we have changed our software to take advantage of features of our new equipment. We found the DOS environment to be too restrictive for our purposes. DOS was initially chosen for familiarity reasons, but running Linux has long been a goal. This year the team decided to make the time investment and port all of the software to Linux. This task was time consuming, but the switchover to Linux was inevitable and worthwhile.

Since it seems likely that the competition objectives will be fairly static for the next few competitions, the team decided that it would be worthwhile to invest this year making modifications that would make the vehicle more robust so that it could serve as a stable long-range platform. Our strategy is to develop a proven autonomous platform that could be built upon to more fully complete the mission objectives in future competitions.

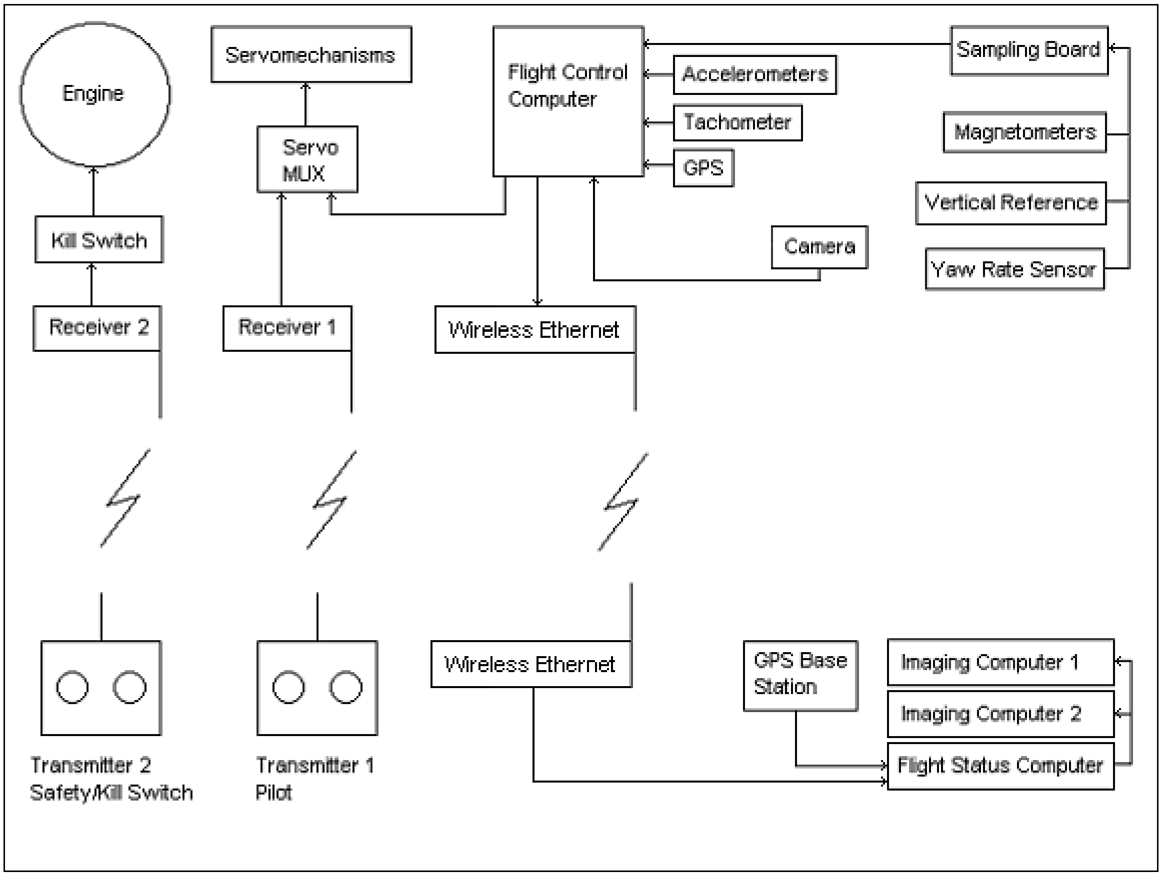

Figure 1: System Diagram 2001

Elegance of Design and Craftsmanship

Several of this year's modifications have reduced the number of separate components in the aerial vehicle. The separate video and data transmitters were consolidated into a single ethernet link, reducing weight and power usage. The new 266 MHz Little Board computer is a tightly integrated package that has consolidated several pieces of hardware. Additional built in serial ports obviate the need for a serial expansion card on the PC-104 stack. The motherboard comes with an integrated video capture card with three selectable video inputs. Thus the video multiplexer from past years, as well as any additional video capture hardware, are unneeded. Built-in support for compact flash storage media, ethernet network interface, and video output further reduce the number of external components.

The aerial vehicle has been built with durability and crash-worthiness in mind. The landing gear was made quite large to prevent rollover on landing. The landing gear is also sturdy enough to absorb a significant amount of energy in a crash, thus protecting the other components on the helicopter. In the event of a minor crash or hard landing, the landing gear can simply be bent back into shape. After a failure of the side frames of the

Bergen occurred, they were replaced with custom-built frames that do not contain the lightening holes found in the standard side frames. This increases weight only slightly but significantly improves the stiffness and strength of the helicopter body. The Kevlar-composite mounting board that supports the electronic components provides more protection to the electronics and is sturdier than past aluminum-rail-based designs.

Innovation in Air Vehicle & Subvehicle Design

Primary Propulsion

The primary propulsion mechanism of the aerial vehicle is a Bergen Industrial Twin model helicopter. The helicopter platform itself weighs approximately 18 pounds, and has a maximum takeoff weight of approximately 43 pounds. This helicopter is a well-proven design that allows the team to focus more effort on developing autonomous control rather than having to reinvent a dependable propulsion mechanism. The team is satisfied with the existing modifications to the original Bergen vehicle including the lightweight Kevlar electronics mounting platform. Lightweight and accommodating of new hardware, the current vehicle configuration has not required a great deal of modification.

Sub-Vehicle

Most vehicle design work has been focused on developing a system for returning images from within the target building. The team's proposed solution is a small autonomous ground vehicle that could enter and navigate within the target building, after being delivered to the site by the helicopter. The planned mounting system for this vehicle is a set of rails beneath the Bergen helicopter from which a vehicle delivery shell with rollers will be mounted. This vehicle shell will surround the sub-vehicle with an impact-absorbing material. A spring loaded firing mechanism between the rails will propel the ground sub-vehicle from underneath the helicopter, through a window, and into the building.

Once inside the building the ground vehicle will operate independently. It will first find a wall and then exhibit a wall-following behavior such that a small camera directed 90 degrees from the direction of travel will always point towards the center of the room. By following the wall, the vehicle will travel from one room to the next and eventually document most parts of the structure. The ground vehicle carries a small CCD camera and video transmitter that relays the image the short distance to the helicopter outside. The helicopter will then digitize the video signal and transmit it back to the base station.

A prototype ground vehicle has been built for testing navigation techniques. The prototype is a three wheeled vehicle equipped with two Sharp infrared ranging devices to track wall distance. The infrared range finders are compact and offer excellent resolution for distances up to 80 cm. The rangefinders' signals are read by a microchip PIC 16C74 microcontroller that controls the vehicle's drive motors. The PIC is the optimal device for the task, with A/D conversion and pulse width capabilities in a single package. The advantage of using a microcontroller to control the vehicle is that it is easy to change the behavior of the vehicle and modify the behavior routines during development.

Attitude & Heading Adjustment Schemes

The helicopter sensors work together to provide the control systems with information on the current state of thirteen basic flight parameters. The differential GPS and accelerometers work in concert to provide accurate information on the current vehicle position and velocities in the x, y, and z directions. Integrated acceleration data is combined with GPS data to better estimate the vehicle's velocity. The accelerometer also provides some fault tolerance in the event that GPS solution is lost, or a broken data link to the ground station stops differential GPS updates. Angular information on roll and pitch come from a Watson vertical reference. Yaw and its rate of change are provided by a Honeywell magnetometer and a Watson yaw rate sensor, respectively. The last parameter is main rotor speed, which is measured with a custom-designed Hall effect sensor.

Each of the thirteen flight parameters has a setpoint indicating the desired value of that parameter. The controllers attempt to minimize the error between the current value and the setpoint of a given parameter. Control of the helicopter is achieved through manipulation of these setpoints. Thus behaviors such as hover or motion towards a given waypoint are created by the manipulation of set points.

The controllers that maintain the desired setpoints consist of a series of fuzzy logic controllers. The parameters of each fuzzy controller can be manipulated from the ground station application HeliClient. This allows fine tuning of the controllers during flight. Higher-level flight mode controllers transition the helicopter through six flight modes that could be encountered during flight. These modes include takeoff, forward flight, hover, land, and special modes that react to various sensor failures. For example, should communication with the ground station be lost, the vehicle's flight mode controllers can automatically begin a landing sequence.

Stability Augmentation Schemes

Several modifications have been made this year that improved the vehicle's stability and made future improvements easier. The combination of the port to Linux and the new hardware has increased the stability of the control software. Linux, being a multitasking operating system, can run multiple processes at once, allowing vital aspects of the control system to run as separate processes. This distribution of the application provides isolation in the event of a software malfunction and also leads to faster development and testing. A past problem encountered during testing was losing GPS solution when shutting down the software in order to make modifications. With Linux, a separate application for the GPS could continue to run independently of the main software application so that GPS solution can be maintained during software updates.

Navigation Techniques

Navigation capability is provided by transitioning between hover and motion flight modes. When the helicopter is instructed to move to a new waypoint, a fuzzy logic mode controller determines the degree by which the outputs of the hover and motion fuzzy controllers should be combined. When the destination is at a large distance the flight mode is mostly in effect, but as the vehicle approaches the waypoint the hover mode behavior is given priority and the helicopter returns to hover mode to wait for a new waypoint. Currently the waypoint navigation has yet to be fully tested under the new computer hardware and software platform.

Risk Reduction and Threat Avoidance Schemes

The helicopter is capable of a controlled decent in the event of systems failures. If differential GPS positioning is lost, the helicopter control software has provisions to minimize its velocity and begin to land unless the condition improves or the safety pilot takes control. Heading and main rotor rpm controllers are unaffected by a GPS failure and a controlled descent is possible.

Another risk reduction precaution is the ability for the ground station to monitor the value of approximately 300 parameters that indicate the current state of every aspect of the helicopter and its control software. This allows the team to remotely view the status of the onboard systems and verify that they are within safe operating limits. In the event of unsafe operating conditions such as low battery levels or a significant loss of GPS solution quality, the safety pilot can intervene before problems occur.

If an unrecoverable system failure should occur, there are two possible responses to protect the safety of observers. The first response is for the safety pilot, who is on constant standby during flight, to flip a manual control switch on the controller that causes the onboard hardware to relinquish control to the pilot. This removes the computer from the control path and the safety pilot can then land the helicopter manually. In the event that the pilot cannot stabilize the aerial vehicle, the second response is a completely independent emergency termination mechanism. The termination mechanism is an independently powered servo controlled by a second transmitter that simply grounds the engine’s ignition coils. This prevents the spark plugs from firing and kills the engine instantaneously, thus rendering the vehicle ballistic.