Rose-Hulman Institute of Technology's Autonomous Helicopter for the 2002 International Aerial Robotics Competition

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Abstract

In preparation for the 2002 International Aerial Robotics Competition, the Rose-Hulman Aerial Robotics Team has revamped many of the vehicle's systems. In order to build a robust and adaptable autonomous platform, several subsystems have been redesigned. Major modifications to the vehicle include a highly integrated hardware mounting system, redesigned modular software architecture, a change in wireless ethernet hardware, and the adoption of Lithium Ion battery technology.

Competitive Strategy

The team's goal for the 2002 IARC is to demonstrate an adaptable robust autonomous platform capable of long-range operation. Our strategy is to focus on the fundamental requirements of the mission, autonomous operation at speeds upwards of 30 km/hr at an extended distance from the base station. The first component of our goal is to demonstrate autonomous takeoff and hover. The second part is to demonstrate waypoint navigation capability by flying the initial 3 km waypoint path. The third component is to verify that the platform is capable of the flight speed required to complete the mission within the fifteen minute time constraint. This strategy will yield a dependable autonomous platform on which more sophisticated behavior can be built in the future.

The design of the 2002 vehicle will aid in the execution of our competitive strategy. Eventual completion of the current mission will require higher flight speeds than in previous missions. The 2001 mounting system, consisting of flat a Kevlar mounting surface, was versatile but not aerodynamic and didn't provide sufficient protection for the electronics. Most importantly, we found that the mounting system acted as an inverted wing in forward flight forcing the vehicle towards the ground. The new mounting system holds circuit board components vertically, creating a slimmer profile and causing less downward force in forward flight.

In order to have an adaptable autonomous platform and to facilitate rapid development, the ideal software system would allow easy modification and addition of functionality. The team found after porting the previous year's software to Linux that the code didn't lend itself to modification between mission objectives and was not easily expandable. As a result, the software system was completely redesigned with a focus on object oriented techniques and providing a core set of reusable components that can then be utilized by mission specific elements.

Wireless communication with the vehicle will be necessary to return images from the target structure as well as to monitor the vehicle's status. The team has replaced the bulky wireless ethernet bridge with a combination of a PC-104 PCMCIA adapter and a PCMCIA Orinoco wireless ethernet card with external antenna. This combination yields significant weight and power savings and still allows the use of a high quality antenna to achieve optimal range.

When the previous Ni-MH battery packs needed replacing, we investigated other battery technologies. Estimating the power requirements of the system, we wanted the battery packs to operate the electronics for at least half an hour at full operation. Lithium Ion cells provide the highest energy density currently available. The low weight and long runtime of Lithium Ion cells justified the extra cost and development time needed to make the transition.

System Overview

The aerial vehicle is composed of mechanical, electrical, sensor, hardware, software, and safety sub-systems. The 2002 vehicle includes many modifications in these systems from the 2001 vehicle design. The system overview shown in Figure 1 shows the main subsystems and their components.

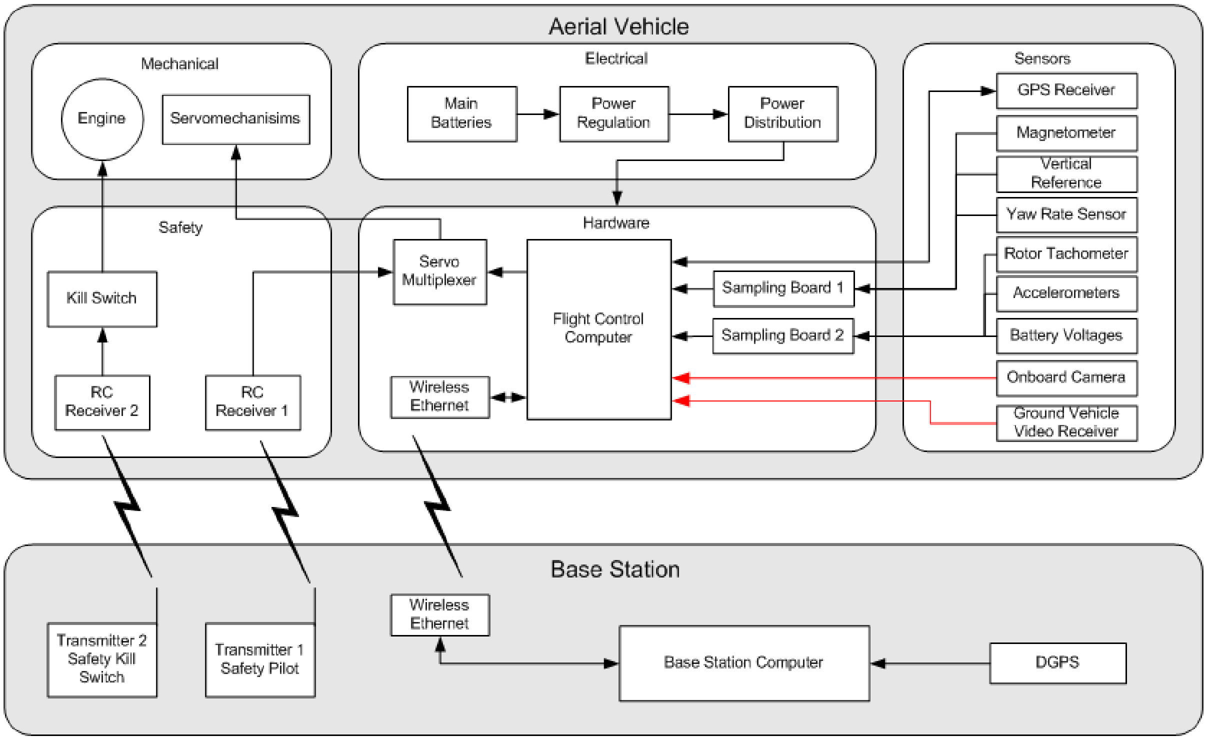

Figure 1: System Overview Diagram

Mechanical Subsystem

Primary Vehicle

The primary aerial vehicle is a highly modified Bergen Industrial Twin model helicopter. Previous modifications to the helicopter include enhanced engine cooling through modified air baffles, a conversion to a single carburetor to ensure balanced fuel mixture in both cylinders, non-perforated side panels for increased airframe rigidity, and a durable custom landing gear. Modifications to the vehicle this year include the replacement of the previous starting mechanism to allow the area directly below the engine to be used for the secondary vehicle payload.

Secondary Vehicle

The secondary vehicle is a tread based ground vehicle that will be delivered to the target via a launching mechanism underneath the helicopter and between the legs of the landing gear. This vehicle will be deployed through the building opening inside a delivery case that will provide impact protection and ensure that the vehicle lands upright. The proposed ground vehicle will carry a small CCD camera and will exhibit a simple wall following behavior, allowing it to travel through all the rooms in the building. The video signals from the ground vehicle camera will be transmitted a short distance to the helicopter, where the image will be digitized and transmitted back to the base station. The ground vehicle is currently in a prototyping stage.

Mounting System

The mounting system has been redesigned to reduce drag under high-speed forward flight and to provide better protection for the sensors and electronic hardware. The system consists of a front and rear unit that can be quickly attached or removed from the airframe. The ability to quickly remove the control intelligence as a unit will make helicopter maintenance and testing easier.

The front mounting unit contains the batteries, power regulation and distribution system, attitude sensors, and GPS system. The rear mount contains the onboard computer, the servo multiplexer, accelerometers, and wireless ethernet. The mounts are constructed from lightweight carbon fiber and kevlar composite. The component mounts are extremely durable and provide excellent protection for the sensitive sensors and electronics.

Electrical Subsystem

With the new mounting system, the wiring system has been revamped to simplify the wiring and reduce the length of cables. The front and rear component mounts are tied together by a single umbilical that carries data and power between components between the front and rear units. The wiring system complements the modular mounting system by creating a single connection point allowing for simple disconnection and removal of the electronic hardware.

Lithium Ion batteries will replace the Ni-MH batteries used in previous designs. Lithium Ion cells offer a significantly higher energy density resulting in longer flight time per charge and less weight. Although care must be taken with Lithium Ion cells to protect against over-charge and over-discharge, the weight savings justify the investment. The new cells have a gravimetric energy density of 160 Wh/kg, nearly twice the capacity of the previous Ni-MH packs.

Sensor Array Subsystem

The onboard sensor array consists of a NovAtel differential GPS receiver, two dual-axis Analog Devices accelerometers, a Watson vertical reference, a Watson angular rate sensor, a Honeywell magnetometer, and a custom hall-effect main rotor tachometer. These sensors are sampled by custom sampling boards, which transmit the data to the onboard computer via serial port. The Watson equipment has been mounted in a vibration isolated cradle to reduce noise and protect the sensors from impact.

Hardware Subsystem

The hardware system consists of a commercial PC104 computer, two diamond systems QMM timer boards, two custom circuit boards, and an Orinoco wireless ethernet card and external antenna. The onboard computer is a 300 MHz Pentium single board computer made by Advanced Digital Logic. The board is a tightly integrated package that has allowed us to consolidate several pieces of hardware into a smaller and lighter package. The motherboard has four serial ports, which is sufficient for communicating with our custom sensor boards, an integrated video capture capability with three selectable video inputs, built-in support for compact flash storage media, Ethernet network interface, and a VGA port among other features. The QMM timer boards are used to generate the pulse width modulated signals for the servos as well as sample the pulse width modulated signals from the accelerometers and safety pilot transmitter. The Orinoco 11Mb wireless ethernet card with external antenna has enabled a data link with bandwidth sufficient for transmitting telemetry data, control commands, and images from the vehicle.

Software Subsystem

The software sub-system has been redesigned using a modular approach to facilitate faster development and to encourage software reusability. The control logic has been isolated from the hardware implementation so future augmentation of the sensor array or underlying hardware architecture will be transparent to the control system. The software has been made more mission-independent by generalizing the main software components and allowing independent client applications to be added to provide specialized functionality. This way, mission dependent functionality is isolated from the basic autonomous platform. This has been done by repartitioning the responsibilities of the onboard and base station applications to remove mission specific functionality from potentially reusable code. Figure 2 below shows the relationship between the main applications that make up the new software architecture.

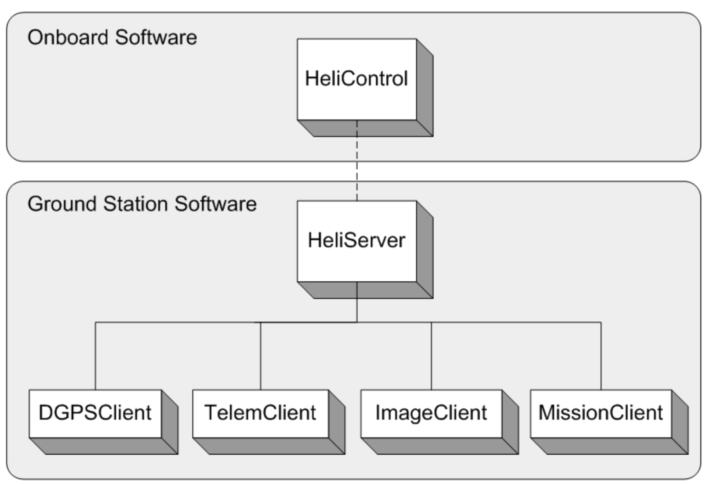

Figure 2: 2002 Software Architecture

HeliControl is the main program that executes onboard the helicopter's computer. HeliControl's responsibilities include obtaining data from the sensors, determining the state of the helicopter, issuing control signals to the servos, and navigating the helicopter. An important part of HeliControl is a reusable component called the registry which provides a hierarchical index of data and functions made available to ground station applications. Ground station applications can subscribe to any parameter or invoke any function made available through the registry. HeliControl communicates through a 11Mb wireless Ethernet link to HeliServer. A suite of client applications then connect to HeliServer and subscribe to data made available through the registry and can invoke methods remotely. Ground station client applications include DGPSClient, TelemClient, MissionClient, and ImageClient. The DGPSClient forwards differential GPS correction logs from the DGPS base station to the helicopter. TelemClient is a GUI application that allows the user to dynamically view and log selected sets of data from the onboard system registry in real-time. MissionClient is the application that is aware of mission specific functionality and provides high-level mission status information. ImageClient will initially allow remote viewing of digitized images from the helicopter and will become the entity in charge of image processing as algorithms are developed.

System Operation

Propulsion

The primary propulsion system is based on a Bergen Industrial Twin model helicopter. The helicopter, equipped with a 4.5 horsepower 46cc Zenoah two cylinder engine, weighs approximately 18 pounds and has a maximum takeoff weight of 43 pounds. The custom fuel tanks allow the vehicle to carry nearly a liter of fuel for a sustained flight time of over thirty minutes. This helicopter has been a dependable aerial platform that has allowed the team to focus on designing a control system rather than perfecting the flight platform itself.

Stability Augmentation

Helicopters are inherently unstable systems that require constant monitoring to achieve even simple behavior such as a hover. In order to attain stable control of the helicopter, the onboard computer samples data from six onboard sensors at rates of up to 500 Hz. Using this raw sensor data, a state model of the helicopter is developed. The helicopter control system understands the state of the helicopter in terms of 13 critical state variables. These variables are the Cartesian x, y, and z positions of the helicopter and the corresponding x, y, and z velocities, the roll, pitch, and yaw angles and their angular rate of change, and the main rotor speed. Inside the control system, each state variable has a setpoint, which represents the desired value of that parameter. These setpoint values are modified by the navigation system to induce motion towards a goal. As in the previous year, the helicopter control system is based on a fuzzy logic control system recommended by Michio Sugeno for a model helicopter (Sugeno 1995).

Navigation

The current navigation behavior is based on following waypoints entered into the flight plan before or during flight. Motion between waypoint goals is built out of simple flight modes such as hover, forward flight, ascent/decent, lateral motion, or rotation. In order to reach a waypoint, the navigation system transitions through the appropriate flight modes, or combinations of flight modes to reach the desired state. For example, to fly to a waypoint directly ahead of the current position, the navigation system starts out in hover mode, transitions to forward flight mode and then gradually back to hover mode as the vehicle approaches the desired waypoint position.

Risk Reduction & Threat Avoidance

The safety of the vehicle and particularly that of any humans in its proximity is of paramount importance. Thus the vehicle has been designed with multiple failsafe systems. The first failsafe system is a manual control mode that allows a safety pilot to regain command of the vehicle should it become unstable under autonomous control. An independently powered servo multiplexer system can select whether computer generated signals or safety pilot commands are sent to the servos. The safety pilot can use a switch on the RC transmitter to instantly gain control of the helicopter servos.

The secondary failsafe mechanism is an independently powered and controlled remote kill mechanism. The device uses a second RC transmitter to actuate a servo that grounds the spark plugs causing the engine to die. In the event that the autonomous control system fails and the safety pilot is unable to stabilize the vehicle through manual control, the safety kill mechanism is employed to protect spectators by bringing the vehicle down immediately.

Conclusion

The Rose-Hulman aerial vehicle for the 2002 International Aerial Robotics Competition has undergone major modifications since the previous competition. Modifications have included a highly integrated hardware mounting system, a new onboard and base station software system, a change in wireless ethernet hardware, and a transition to Lithium Ion battery technology. Our strategy for the 2002 International Aerial Robotics Competition is to demonstrate an autonomous platform capable of fulfilling the fundamental mission requirements including an autonomous high-speed flight across three kilometers to the target structure. This strategy will provide the team with a proven autonomous platform from which further mission objectives can be achieved.

References

Sugeno, M. 1995. “Development of an Intelligent Unmanned Helicopter.” Tokyo Institute of Technology. Yokohama, Japan.