A Purpose-Built Robot for Aerial Surveillance

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ABSTRACT

An autonomous aerial robot is being developed at the University of British Columbia (UBC) for entry into the Millennial Event of the International Aerial Robotics Competition. The purpose of this competition is to survey a natural disaster scene and identify human casualties and hazards to a manned rescue effort. This paper documents the third generation robot which builds upon knowledge gained from the first two attempts to produce a practical, working vehicle.

The approach taken by this aerial robotics group was to develop an easily controllable vehicle to facilitate the control software, rather than developing complex control software for an existing vehicle. The UBC robot consists of seven propellers: one main propeller centered around six small control propellers. The vehicle is capable of vertical takeoff and landing, hover, and translation or rotation in any direction.

The embedded system was designed to control the craft in task space before the control action is mapped onto the seven actuators. The controller keeps the craft flat and level in all movement modes using the horizontal thruster to translate and rotate in the horizontal plane and the vertical propellers for height and stability control.

To accomplish the task of recognizing and locating human casualties and hazards, an image recognition system will analyze pictures obtained from a high resolution camera system attached to this platform. Although the vehicle will be programmed to perform a search pattern given a fixed boundary, the waypoints can be modified in real-time by the navigation program to concentrate on areas of interest.

INTRODUCTION

This paper discusses the third generation aerial robot being developed by the University of British Columbia (UBC) for entry into the International Aerial Robotics Competition Millennial Event. The vehicle must be capable of autonomously surveying a simulated disaster scene from the air, and identifying human casualties, toxic waste barrels, fires, and other potential hazards to a manned rescue effort. The UBC vehicle will compete fully for the first time at the 2000 qualifier.

The UBC vehicle consists of seven propeller (one main propeller centered around six smaller control propellers) all running off one 17 hp engine (figure 1). This control configuration allows for vertical takeoff and landing, hovering, and translating or rotating in any direction. On-board sensory equipment for stability and navigation include an inertial gyro, differential GPS unit, and sonar. An image recognition system will analyze digital pictures captured from an onboard camera.

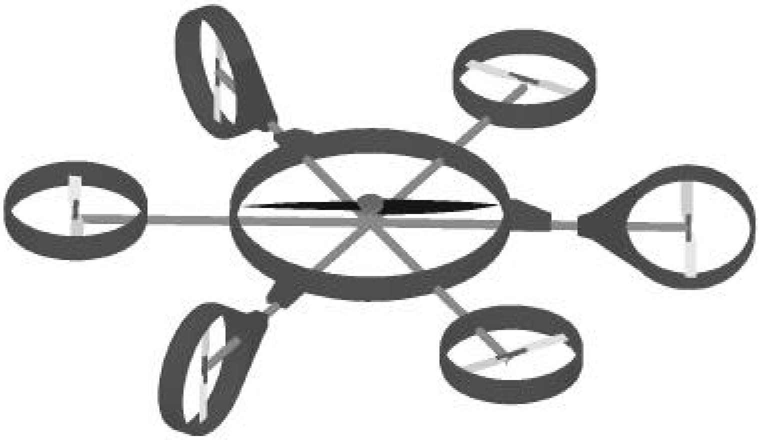


Figure 1: UBC Aerial Robot

Various aspect of the UBC vehicle will be discussed including competitive strategy, aircraft and mechanical design, sensory and control systems, .

COMPETITIVE STRATEGY

The challenge of the International Aerial Robotics Millennial Event is to survey a natural disaster scene and identify human casualties and hazard to a manned rescue effort. To accomplish this, a stable aerial platform with onboard sensory components must be developed.

Previous attempts at completing this challenge by other universities have focused around developing computer controls for an existing model helicopter. Although helicopters have been flown successfully under human control for many years, they were not designed for artificial intelligence and thus have proven to be difficult to control via a computer.

To overcome this control difficulty, UBC has developed an alternative air vehicle. Although this vehicle would be impossible to fly under human control, stabilization and movement schemes via a computer is greatly simplified. This vehicle consists of one main propeller centered around six smaller control propellers all running off one 17 hp engine. From initial trials of this concept in previous year, its potential to maintain stability of an air vehicle was proven.

To identify human casualties and other ground hazards, an image recognition program is being developed. This program will accept high resolution images from an onboard camera with processing occurring on a ground computer. The routine will involve first looking globally at a large area to determine if there is anything of interest. If possible targets are found, waypoint information will be updated to return back to the area of interest and further study the area.

VEHICLE DESIGN

The design of the UBC aerial robot can be separated into two challenges: 1) design of the aircraft and mechanical systems and 2) design of the sensory and control systems. Many previous attempts of designing an autonomous flying vehicle have focused primarily on the control system and relegated the design fo the craft to a secondary role. In most cases, an off-the-shelf model helicopter was used. Although this approach eliminates the need to develop a vehicle, the control system becomes extremely complex. With the entire problem being considered, designing an optimal mechanical vehicle with a simpler control system become advantageous.

AIRCRAFT AND MECHANICAL DESIGN

The aircraft design was divided into two categories. The main and most important category was all mechanical systems required for flight under normal operating conditions. Secondly, mechanical designs were implemented for risk reduction to both the vehicle and bystanders given an emergency condition.

Flight

The UBC aircraft was designed to facilitate two important flight objectives: takeoff and landing within a designated zone and maneuvering to avoid obstacles and position itself to observe ground targets. To accomplish the first goal, the vehicle was designed for vertical takeoffs and landings. The second goal was achieved by designing the vehicle to be capable of hovering and translating and rotating in any direction. To satisfy the above criteria and to simplify the control system design, a craft was developed that consisted of six control propellers centered around one main propeller.

The power plant for all the propellers is a 17 hp Quadra-Aerrow engine. The main propeller is connected directly to the engine shaft. At the expected operating speed of 9000 rpm, the thrust from the main propeller is approximately 50 lbs (90% of expected aircraft weight). The six control propellers (three vertical and three horizontal) are connected to the main shaft by 3 belt drive systems with a constant 1/3 speed reduction. Each belt drive system is responsible for one horizontal and one vertical pod. On startup, they are isolated from the engine through centrifugal clutches. Variable force is obtained from the six control propellers by changing the collective pitch of the blades. Figure 2 shows one type of control propellers on the robot.

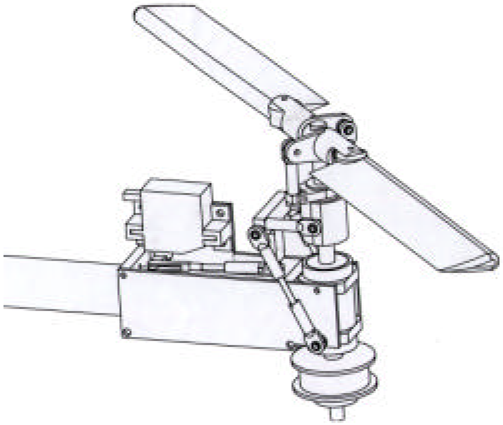


Figure 2: Horizontal Control Propeller

The three vertical control propellers are mounted at 120 degree intervals around the center of the craft. These are used for vertical translation and roll and pitch control. Testing showed that these have a variable force range of +/- 6 lbs. The three other control propellers are mounted horizontally and used to control the yaw of the vehicle and translation parallel to the ground. Testing showed that these have a variable force range of +/- 4 lbs.

Of interest with the vertical control propellers is a custom designed servo mechanism to actuate the variable pitch device. Inadequacies of current commercially available hobby servos to respond to input from the flight control system made is necessary to develop a new servo mechanism with a height response time. The developed servo consists of a lead screw assembly connecting a micro DC motor to the variable pitch device lever. Running a closed loop analog PD circuit, it has a worst-case response time of 35 ms given a worst-case travel scenario.

Risk Reduction

In case of an aircraft malfunction, the UBC vehicle is design to minimize damage to itself and to bystanders. Ducts around all of the propellers ensure that any damage from the propeller systems are contained within the ducts. A landing gear (Figure 3) was designed for this vehicle to survive a worst-case drop from 12 ft and hitting the ground at 36 G's. Impact energy is absorbed using an aluminum honeycomb base. In addition, carbon fibre rods extend out from the center base to produce a larger landing base.

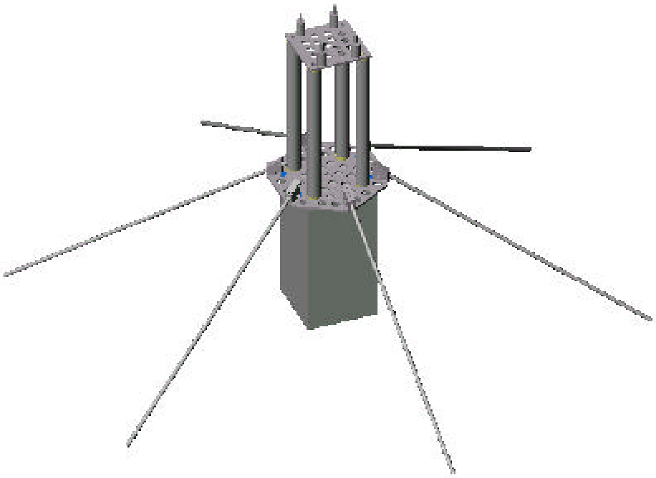


Figure 3: Landing Gear

Although the “kill switch” is part of the electrical system, it will be discussed here as it contributes to the risk reduction for the aircraft. The kill switch allows a human operator to disable the aircraft in any situation. The UBC aerial robot is essentially disabled when the main motor is disabled. This is done by placing a relay on the line connecting the engine battery to the spark ignition system. Switching the relay is done across a separate radio relay (Linx Technologies RM Series) by a push button on the ground.

SENSORY AND CONTROL SYSTEMS

The electrical systems associated with the UBC vehicle consists of an on-board system, a ground system and a communication link between them.

On-Board System

The on-board system’s primary responsibility is to maintain level flight and is discussed in detail in the subsequent section. It’s secondary responsibility is to synchronize events with the ground station over an RF data link. The philosophy behind developing the system was to allow the robot to maintain its position and stability under extended failure of communication medium. Using this rule, all information needed to maintain the craft in flight is collected, processed, and acted upon on-board the vehicle. To make the on-board system simpler, and thus more robust, all information needed for mapping, route planning, and obstacle avoidance is transmitted to the ground computer for processing.

Stabilization

At the heart of the stabilization hardware is a six-axis inertial measurement system which measures the vehicle’s angular position and velocity. Height information is obtained from both a sonar system giving relative distance from the ground and a DGPS system giving an absolute reading. The DGPS system also provides the control system with location information. Rotational data is acquired from a flux gate compass.

The control system uses a separate PID loop for each degree of freedom with a very slow pre-filter for the reference commands. This design has been verified on a custom simulator and can successfully fly the craft under strong simulated winds. However, the system was found to be very sensitive to modeling errors in the center of gravity and cross-coupling due to off-diagonal inertia elements as these are ignored in such a design.

The loops had to be de-tuned considerably to allow sufficient uncertainty and as a result are somewhat sluggish.

Because the inertia and center of gravity of the craft are not well known a controller that is more insensitive to these parameters was desired. A lesson learned from the simulator early on was the futility of manual control – an attempt at switching from automatic to manual is shown in Figure 4 below. For these reasons an H_∞ design is being developed using the GRIBS 6-DOF simulation tool which allows for manual override while maintaining automatic pitch and roll control. The control structure is shown in Figure 5 below.

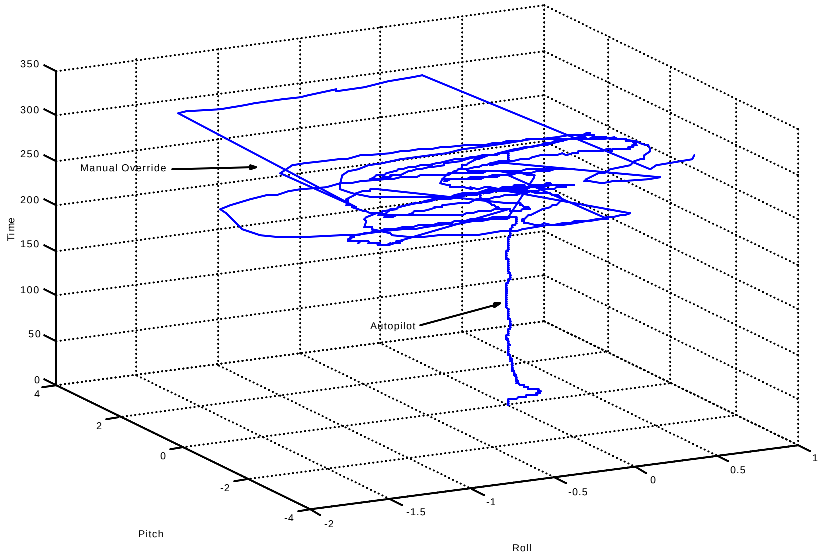


Figure 4: Automatic vs manual control of attitude

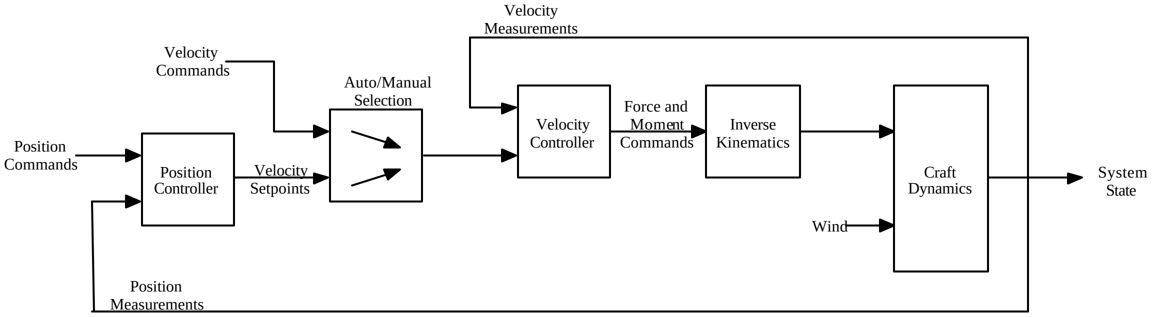


Figure 5: Control structure

As shown above, the embedded system was designed to control the craft in task space before the control action is sent to augment the engine RPM and the pitch on the six control propellers.

Communication

The primary link between the on-board computer and the ground computer is a 900MHz wireless modem module. This link has two purposes:

- Provide the on-board computer with waypoint information
- Transmit all sensor data to the ground station for processing, recording, and presentation

As mentioned before, the on-board systems have been designed to operate without any information from the ground. In case of a communications failure and no information is received, the vehicle will maintain it's current position in a stable hover. This will continue until the data link is re-established and new waypoint information is sent from the ground computer to the on-board computer.

Ground System

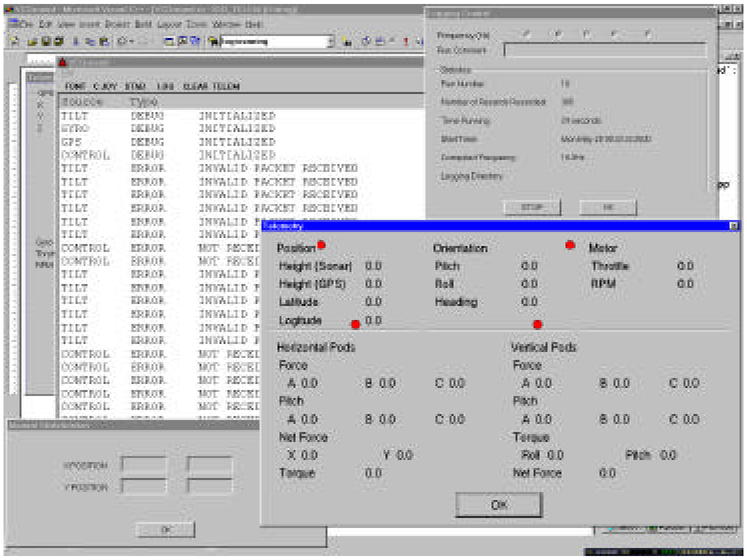
The primary responsibility of the ground station is to provide waypoint information for the on-board system. It's secondary responsibility is to log and display all the telemetry and sensory data from the vehicle. Upon completion of an image recognition system for target identification, a second ground computer will be responsible for target identification.

Navigation

An initial set of waypoints is setup by giving the navigation program a search boundary. Waypoints can then be altered manually to fine-tune a search pattern. In operation, the vehicle will first be told to complete the initial search pattern before returning to any areas of interest as indicated by the image recognition system.

Telemetry Data Logging and Display

A graphical user interface has been developed that displays all the vital statistics of the vehicle, including altitude, orientation, location, and velocity. This is shown in figure 6.



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SOURCE    TYPE
TILT      DEBUG    INITIALIZED
GYRO      DEBUG    INITIALIZED
GPS       DEBUG    INITIALIZED
CONTROL   DEBUG    INITIALIZED
TILT      ERROR    INVALID PACKET RECEIVED
TILT      ERROR    INVALID PACKET RECEIVED
TILT      ERROR    INVALID PACKET RECEIVED
TILT      ERROR    INVALID PACKET RECEIVED
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CONTROL   ERROR    NOT RECEI
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Position ●
Height (Sonar) 0.0
Height (GPS) 0.0
Latitude 0.0
Logitude ● 0.0

Orientation ●
Pitch 0.0
Roll 0.0
Heading 0.0

Motor
Throttle 0.0
RPM 0.0

Horizontal Pods
Force
A 0.0 B 0.0 C 0.0
Pitch
A 0.0 B 0.0 C 0.0
Net Force
X 0.0 Y 0.0
Torque 0.0

Vertical Pods
Force
A 0.0 B 0.0 C 0.0
Pitch
A 0.0 B 0.0 C 0.0
Torque
Roll 0.0 Pitch 0.0
Net Force 0.0

Figure 6: Ground Station GUI

A similar GUI for the image recognition and target identification is displayed on the secondary ground computer.

CONCLUSION

The focus of the Aerial Robotics Team at the University of British Columbia has been to develop an autonomous aerial platform capable of vertical take-off and landing, hover, “planar” motion. An innovative vehicle consisting of a main propeller centered around six smaller control propeller has been developed. An on-board sensory and control system consisting of a single board computer and various sensors (inertial gyro, compass, sonar, and DGPS) is responsible for the stability of the vehicle. The embedded control system was designed to stabilize the craft in task space before the control action is sent to augment the engine RPM and the pitch on the six control propellers. Measures to ensure the safety of the vehicle and bystanders were also design in the event of a system malfunction. A ground computer is used to provide the on-board system with waypoint information and log and display telemetry and sensor information from the vehicle.