Technical Paper for International Aerial Robotics Competition

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Abstract

The International Aerial Robots Competition (I.A.R.C.) is designed to challenge students and industry to work together to achieve a common goal. This goal is to survey a simulated disaster site and determine the location of survivors and potential hazards. To accomplish this, the DeVry team has incorporated a multi-unit system that consists of both aerial and terrestrial units. By using a wireless communication system these autonomous vehicles are capable of interacting with one another to complete the required elements of the competition.

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1.0 INTRODUCTION

A disaster scene can be an extremely dangerous and unpredictable place. The International Aerial Robots Competition was created to challenge students, often working in partnership with industry to come up with new and innovative ways of dealing with disaster sites while minimizing further risk to human life. The landscape for the competition contains wreckage, fire, smoke, simulated survivors, and other unknown obstacles to make the challenge realistic. With each successive year of competition, new technical challenges are added and expectations for competing teams are expanded. As DeVry Calgary team enters their fourth year in this competition, Team 2000 has incorporated previous years' experiences with new and innovative solutions for the 2000 competition. To achieve success, Team DeVry uses a competitive strategy, an innovative system design, hi-tech modem communications, increased safety, modern navigation (GPS), and target identification techniques.

2.0 COMPETITIVE STRATEGY

Team DeVry's strategy is to use an autonomous helicopter and a ground vehicle that work together to locate and map the potential dangers, to search for and rescue potential survivors, and provide an overall assessment of the disaster site without risk to human life. By using the helicopter, Team DeVry will be able to quickly survey a large area of terrain, find survivors and send their locations to the ground unit for investigation. Since the helicopter will not be able to get close enough to the victim, the advantage of having the ground unit is that it will be able to help the victim by pin pointing the location for a human rescue team and by leaving a first aid kit or other needed supplies until suitable help arrives.

3.0 AERIAL UNIT

3.1 Mechanical System Design

The aerial units in the DeVry entry for I.A.R.C. 2000 consist of one X-Cell radio controlled helicopter and one computer controlled Bergen helicopter. The X-Cell 60 Class helicopter was chosen as a test bed for the electronic systems that were developed, and will be used for back up to the Bergen in the competition. The Bergen was chosen because of its durable airframe and many up-gradable components.

The Bergen airframe itself has had many modifications such as a larger engine, bigger muffler, lengthened tail boom, extended main shaft and longer blades. All these modifications were necessary to increase the maximum payload it can carry. The Bergen Twin will be the aerial unit used in the competition. It is a radio-controlled industrial helicopter weighing twelve pounds, with a gasoline-burning engine and a maximum payload of eighteen pounds excluding fuel. The Bergen is capable of flying for thirty minutes without refueling, and is highly durable and impact-resistant due to its graphite frame construction and reinforced rotor head. Another modification done for the competition was replacement of the plastic tail assembly with anodized aluminum. This was done to solve the problems previous teams encountered due to heat. This will make the helicopter more durable in extreme conditions, and help to ensure success of the mission.

3.2 Electronic System Design

The electronics incorporated into the helicopter include PIC microcontrollers, a video system, a multitude of sensors, wireless modems, and servomotor control units.

The electronic systems on the mobile unit are powered by two 9.6 volt, 3600 mA/hour batteries, which are connected to voltage regulators to provide power to the individual on-board systems. Each battery is comprised of eight 1.2 volt nickel metal hydride cells, and weighs 424 grams. The battery life per charge cycle is conservatively estimated at 1 hour 45 minutes at a 2A load. According to manufacturer specifications, the batteries are expected to last between 300 and 1000 charge cycles. Nickel metal hydride batteries were chosen for their safety, reusability, and resistance to the "memory effect" which is a common problem with nickel cadmium batteries.

Five servomotors or "servos" control the five different aspects of flight: pitch, roll, throttle, collective (blade angle), and yaw. The servos operate on a 5 VDC power supply, and are controlled by means of an input pulse, which varies in duration. The longer the duration of the high pulse, the greater the servo angle. These servos are interfaced to the microcontroller through a Servo Controller Board. This reduces the amount of code needed and simplifies the control of the servos.

Last year's team used a Pentium CPU to realize the main fight control and interface. Because of the weight of the motherboard and the power supply, along with the problems interfacing to certain sensors, the Pentium CPU based system was replaced with a PIC microcontroller and a small 5 volt regulated power supply. The PIC microcontroller allows for simple interface to all sensors used. All code can be written using C mixed with assembly for simple and efficient code. The microcontroller chosen uses RISC architecture, is clocked at 20 MHz, has 22 I/O ports, as well as supporting numerous serial interface protocols. The features of the microcontroller were chosen to make the main control system small and light weight, but at the same time still operate fast enough to read from various sensors and react to the collected data.

3.3 Sensors

The primary sensor aboard the helicopter is the Polaroid 6500 sonar and ranging module. The basic object detection system consists of a sonar-pulse sensor system mounted on a movable base allowing it to ping a forward facing arc to detect obstacles within the flight path. A similar system is mounted on each side, so that after detection, the obstacle can be avoided until a safe distance is placed between the helicopter and the obstacle. The helicopter will have an understanding of its own flight envelope, including its' rotor size so that when plotted, the flight path allows the helicopter to avoid any potential hazards. The range of this sensor is approximately 37 feet (10 meters). To complement the sonar detection system there is an array of downward facing infrared emitters and detectors so the helicopter can take off and land with success. A thermal sensor has also been incorporated to detect heat sources, which could be dangerous to the helicopter.

As well in previous years, all navigational information was provided to the helicopters through the TCM2 card, which incorporated a tilt detector along with the directional compass for navigational control. Because of the TCM2 card's susceptibility to static electricity, vibration, and its high cost, it was decided that it would be replaced. The tilt detection will be realized with two ADXL-202 tilt sensors. Each sensor measures tilt on two axes, and by placing one sensor on the front and one on the side of the helicopter, tilt in all directions can be detected. The direction of the helicopter will be determined with a Vector-2XG digital compass, which has a resolution of 1° and compensates for a small amount of tilt. With simple code implemented on the microcontroller, this new design will surpass the TCM2 card in operation, accuracy, and resistance to external factors like heat, static, and vibration. These sub systems are all linked to the main flight microcontroller and work in conjunction with the Global Positioning System (GPS) to insure accurate mapping of the environment within the disaster site.

The software developed for the sensors requires the system to rotate through the sensors one at a time, sending a pulse and receiving the results in step-wise fashion. The exact time the pulse takes to travel to and from the sensor in microseconds is calculated and multiplied by the speed of sound to give the distance to target. If there is no return signal within a specified time then the target is considered 'out of range'.

4.0 GROUND VEHICLE

4.1 Mechanical System Design

The 2000 I.A.R.C. competition incorporates the latest in not only aerial robotics but also land vehicle technology. The DeVry ground unit for 2000 contains the latest in autonomous land robot technology. Last years effort was the first step in creating a fully artificial intelligent land robot and proved to be beneficial in developing this year's vehicle. Creating a ground unit is not the main object of the I.A.R.C. competition but only a sub system, which is in place to aid the reconnaissance capabilities of the helicopter. After the helicopter has successfully detected a live victim on the ground, specific GPS coordinates are sent to the base station where they are then rerouted to the ground unit via a wireless modem. The ground unit then comes alive and begins its assault on saving the proposed target. However creating an autonomous ground unit is not an easy task. Propulsion termination, navigation, obstacle avoidance and safety systems must be developed in order to avoid mishaps, which are always a possibility. A solid frame must also be in place to hold all of the sensitive electronics. In order to achieve success in rescuing a stranded person from a dangerous obstacle course, the ground unit must posses several artificially intelligent systems. The systems found on board the 2000 ground unit are as follows: a vision system, a GPS module, a network of sonar sensors.

The I.A.R.C. 2000 ground unit is slightly larger than its predecessor. With over all dimensions of 40 inches (width) by 50 inches (length), this ground unit is able to handle heavy-duty loads. In fact it has the ability to carry a 300-pound payload and maintain a top speed of 10kph. The frame is constructed with 1 inch square steel tubing. It uses two 3.5 HP gasoline engines to power the rear wheel. One engine is used to drive the chain mechanism forward and the other drives the vehicle backwards. Both of these engines use centrifugal clutches to maintain constant and even power distribution.

One of the predominant innovations on the ground unit is the incorporation of a sophisticated termination system. A large round red termination button is located on the right rear side of the ground unit about 3 feet off of the ground. This button is for emergency use only and will turn off all of the electronics systems and engines if pushed. There is also an emergency termination program built into the integrated computer system to allow for just a software kill and not a complete termination of the engines.

4.2 Electronic System Design

The ground unit is controlled by an onboard computer system. The computer system consists of a mini-Pentium 120MHz mother board with integrated cd-rom drive, floppy drive, hard disk drive and power supply. The computer controls a serial port expansion card with two extra ports. All four of the ports are nine pin RS-232 serial ports. The first two ports control two sonar controller boards that are attached to Polaroid sonar sensors. The third serial port is used to import GPS strings from the NovAtel GPS transceiver. The fourth port controls the servo controller board, which is connected to both the throttles on the engines and the steering motor. All wireless communications between the land rover and base station are done so using WI-Lan wireless modems (please refer to section 5.0).

4.3 Sensors

The network of sensors found on the 2000 I.A.R.C. ground unit consist of two Polaroid 6500 sonar sensors and two front mounted tactical bump sensors. The Polaroid 6500 sonar sensors function in the same way as the ones on board the aerial units however they are mounted horizontally instead of vertically (please see section 3.3 for more detail on the Polaroid 6500 sonar). The bump sensors are mounted directly to the front bumper of the ground unit. If the sonar does not detect an obstacle in front of the ground unit and the ground unit hits it, then the bump sensors will terminate the engines and stop the ground unit from causing any damage to the object or itself.

A sophisticated vision recognition system has been integrated with the ground unit's central computer. Although the hardware used is the same as that on the aerial unit, a different program will be used to identify objects. Because the ground unit has to be able to navigate terrain as well as identify victims, the program will have to be slightly more complex in its fuzzy logic control system. The ground unit is also able to navigate an obstacle course while driving in between specific marked lanes. Please refer to section 6.0 for more information on vision system dynamics.

5.0 COMMUNICATIONS AND POSITIONING

DeVry uses NovAtel sponsored GPS equipment. NovAtel was chosen for their high precision electronic devices that were easily incorporated into this year's design. The high precision equipment allowed the system to achieve a level of accuracy of 1cm. This new found accuracy is a direct result of the US military (DARPA) directly turning of the deviation codes in the GPS carriers. Our equipment track C/A code that is provided from 24 orbiting satellites set up by the US department of defense. C/A is available to all civilian receivers. Our equipment is also able to receive L1 and L2 carrier phase pseudo-orange code. These are signals that operate at different frequencies. And the sophisticated NovAtel transceivers use the carrier as a way to precisely measure the delay from the precise atomic clocks that are located some 11, 000 miles above the earth in the satellites themselves. After many careful calculations the carrier is used as reference to determine where the data would be on that signal.

The WI-Lan Hopper wireless modem is used as a data link to transfer commands and information between the base station and the mobile unit. The mobile unit transfers its three-dimensional positional data to the base station, along with the recorded altitude from the Earth's surface according to data from the Polaroid sensors. This data is then transmitted upon request by polling the base station.

Located within the base station, the autonomous programming is the heart of the software. The program provides the collection point for the data received from all the applications; it is then assessed and dealt with accordingly. The program takes the current position and speed from the GPS module and uses it to calculate the desired course and course corrections. The software program also acquires object information from the image recognition system. Receiving information from the sensors and other devices, the program uses all the collected data to adjust the servomotors to make appropriate corrections to the course and target.

Spread spectrum technology will be used to transmit the data back and forth in encrypted packets. This hopping technique used by the wireless modems will frequently change the frequencies that are being ensured a high level of security when actuating data. Two distinct frequencies have been chosen to avoid interference between our network of base, aircraft and landrover. 2.4GHz and 900 MHz will be used, both which operate in the mathematical and scientific unlicenced bandwidth.

A base station is set up to find an average position here on earth. NovAtel will be surveying the hammer site to provide us with an extremely accurate position. With help from a known geo-deosic point near the site a position will be provided for us to help our autonomous craft chart around the hammer-site. This known position will be programmed into our base station, which will then be used in conjunction with differential GPS for the aircraft's intelligence system to be able to know where the craft is located at all times.

Equipment

DeVry uses [2] – RT2 NovAtel OEM GPS transceivers, one on board the aircraft and the other as a reference point at the base station. These 2 cards will also be tied into the landrover, which uses [1] – RT20 NovAtel OEM GPS transceiver, to complete an overall system.

The GPS co-ordinates will be feed into the helicopters on board microprocessor system. There the continuous data stream will be parsed out; to give the helicopter it's required data to stay in the air. Longitude, latitude, and height will be the main focus of interest of data being log on the system. Again the Wi-Lan wireless hoppers will be used to complete the wireless system. These hoppers will be used to transmit the correction data to the flights intelligence system.

Although the WI-Lan Hopper is extremely heavy due to its steel casing, the extra weight is being used to advantage. Since the Hopper has high durability, it will be on the bottom of the craft, and will protect the more sensitive components. It will also help to balance and stabilize the mobile unit by providing an extremely low center of gravity. Thus, the "disadvantages" of the WI-Lan Hopper (weight, bulk, and steel construction) have been turned into "advantages".

6.0 VISUAL RECOGNITION

The image recognition system is the "eye" of the aerial robotic system. It is composed of a color Charge Coupled Device (CCD) video camera, a wireless video transmission system, a video capture card, and image processing software. Images captured by the camera mounted on the helicopter are transmitted to a base station for processing. Once at the base station, the video images are digitized using the video capture card and saved into a bitmap (BMP) file.

The image processing software uses several techniques to extract important information from the video images. Detection of objects in a video frame is accomplished using a thresholding and erosion process, which removes details from an image. This "simplified" image contains basic outlines of objects viewed by the camera. The sizes and positions of the objects are recorded in a table, which forms the basis for the rest of the image processing. Objects that are very small or that are on the edge of the frame are discarded from the table. Positions of the remaining objects are plotted against the original image to determine their color. Objects of "uninteresting" colors are discarded from the object table. This leaves a list of "interesting" objects that the system will track. Interesting objects are compared to a small database of images, such as hazardous waste symbols or barrels, to identify important objects.

Object tracking is achieved by comparing positions of interesting objects in successive frames. Motion of objects can be detected by comparing the changes in position of one object to the positions of rest of the objects in the frame.

The image recognition algorithms are tightly combined with mapping routines to provide a detailed picture of the helicopter's surroundings. Exact positions of objects can be extracted from GPS coordinates obtained from the helicopter. In the future, much of the image processing and mapping will be ported to Digital Signal Processors (DSP). As most of the image processing code uses DSP algorithms, this should be a fairly easy process.

7.0 SAFETY AND RISK REDUCTION

The rotary blades of the Bergen Twin helicopter are the primary propulsion system of the DeVry aerial unit. The horizontal rotary blade is isolated by means of a crash hoop, and the tail rotor is isolated by means of an extended protective vertical barrier that extends more than three centimeters below the lowest possible arc of the tail rotor. Unless the robot crashes at an angle greater than 45 degrees to the correct side, or there is an immobile vertical object directly in the path of the tail rotor outside of the tail rotor barrier, a tail strike is not possible.

The credit for the next mechanical safety feature belongs to Larry Bergen of Bergen Machine and Tool, who designed and manufactured the Bergen Twin Industrial R/C Helicopter. One of the many innovations on all Bergen helicopters is the metal rotor head connecting the main shaft with the propeller blades. This metal rotor head contains three separate bolts to fasten the rotary head to the main shaft. Even if one bolt vibrates loose or breaks off, the rotary head of the helicopter will not disengage regardless of the speed or force at which it is rotating.

The most important safety system housed in all entries created by Team DeVry is the Emergency Termination System. This system will be the backup control and shutdown of the air/ground-based units should a problem arise. The termination system is designed so that a range of terminations can take place. During normal operation the system will allow typical data traffic from servo to control board. When the first level of termination is activated, the system will disable the computer control system and allow manual input of commands from a typical radio control source. This way an operator can take control of the systems manually should the computer fail. The second level of termination will be a complete shutdown of the units. There will be a connection, which can be disengaged, from the termination system to the ignition coil of the aerial units' engine. In the case of the ground vehicle, this connection is to the braking system.

8.0 CONCLUSION

When an environmental disaster occurs, time is of the essence. By having an autonomous robotic response team to compliment a human intervention team, the reaction time is reduced significantly. A human rescue team has to develop a strategy before going out into a hazardous, life-threatening situation. This time used to develop strategies can be costly in these types of situations. The autonomous units can be ready to go in a rapid-response scenario. This could potentially save the lives of both the victims and rescue team members.

The DeVry I.A.R.C. 2000 team has had to over come a lot of financial adversity over the last twelve months. However, both the aerial and ground robots designs reflect what one can do with limited time, support and resources. The simplicity and compact nature of the aerial robots PIC micro-controllers and the modular construction of the ground unit can truly be considered groundbreaking technology.