October 29th, 2001

Dr. Andrew Rawicz  
School of Engineering Science  
Simon Fraser University  
Burnaby, BC  
V5A 1S6

Re: ENSC 340 Design Specifications for and Automated Hovering Helicopter

Dear Dr. Rawicz:

We’ve attached our Design Specifications for our ENSC340 project, “Autonomous Hovering Helicopter”, along with this letter. The Design Specifications contain details of control system modeling, hardware and software. Further, the major hardware encompassing the helicopter and the sensors will be described in some detail. The functioning of these components as a system will enable a modified RC helicopter to hover autonomously for a specified period of time.

Moreover, our Design Specifications may have to be reconfigured depending upon the testing and implementation success in the latter stages of the project. Some of the output data from our sensors may be affected by the operation of the hovering helicopter.

Our HAWCS© team contains a talented and cohesive group of engineers – Shahin Roboubi and Jimmy Tsai, two embedded system programmers / Linux specialists, Michael Adachi and Michael Mierau, two control system engineers, and Neil Patzwald, the hardware specialist. Furthermore, if you have any questions or suggestions related to the project for us, please feel free to send an email to our team at arg-heli@sfu.ca.

Sincerely,

Jimmy Tsai  
Project Manager,  
HAWCS, Inc.

Enclosure: Design Specifications for an Automated Hovering Helicopter
Design Specifications for an Automated Hovering Helicopter

Project Team: Michael Adachi
               Mike Mierau
               Neil Patzwald
               Shahin Roboubi
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Submitted to: Andrew Rawicz
Date: November 5, 2001
Recent developments in World politics may have increased the significance in the development and marketability of the small autonomous controlled aerial vehicle. Unfortunately, the initial development phases of the project focused on assisting civilian rescue personnel in lifesaving techniques without further risk to rescuers. However, these advantages can be paralleled to assist military personnel to gain valuable strategic data without the risk of human life, thereby increasing the usefulness of the autonomous control of an aerial vehicle. Further, additional benefits can be realized through reductions in equipment, training and operating costs. Due to the relatively small size of our autonomous flying aircraft and the ease of outfitting the payloads to suit several applications, we now expect greater demand and increases in available research funding.

The development of the autonomous control of an aerial vehicle will consist of three stages, of which we hope to cover the first two in this project and the final stage in the coming spring of 2002. In the first stage of development, our project group will produce an aerial model that will react to sensor feedback when tilted and compensate with rotor corrections in a static testing mode. This testing will assure that the hardware and software are working in unison to provide the required functionality and reliability to ensure that there will not be any damage to our helicopter in flight tests. Therefore, successes in the initial stage will lead to quicker second stage development, consisting of flight-testing to demonstrate the finely tuned features resulting from the static testing procedures. In the spring of 2002, the third stage of development will consist of a programmed autonomous flight with no user input.

This document will detail the hardware and software configurations of the sensors and control unit, which are required for autonomous flight of our helicopter.
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1. Introduction

With the advent of global positioning systems and continued miniaturization of electronic components, computers of smaller payloads may be integrated as control systems on miniature aircraft. These miniaturized systems have recently provided video links to police and fire services to provide search and rescue assistance without the endangerment of human lives in the process. Further, recent developments in World politics may have increased the significance in the development and marketability of the small autonomous controlled aerial vehicle. Moreover, advances in navigation systems and feedback control are now being integrated by the Aerial Robotics Group (ARG) from Simon Fraser University School of Engineering Science in this course project, to provide the first step in the autonomous flight of a small unmanned helicopter.

The Aerial Robotics Group from Simon Fraser University was first entered the International Aerial Robotics Competition in 1997, placing 4\textsuperscript{th} out of 10 teams. At that time the team demonstrated short autonomous flights with a computer-controlled balloon; however, since that time the development has shifted to airplanes and recently to a helicopter in the goal to demonstrate autonomous flight. However, without adequate development time in the recent 2001 competition, the initial step of autonomous flight in the form of a self-hovering helicopter was not accomplished. Therefore, the objective of our project is to provide further development in the initial stages of the autonomous helicopter in the form of self-hovering capabilities.

This document is provided to detail the Design Specifications for an Automated Hovering Helicopter. Details of hardware components will include flight and sensor hardware descriptions. Further, the development and the requirements of the system software will be detailed.
2. System Overview

Our project is centered on a series of control systems performing the adjustments required to maintain helicopter’s stability. The control systems allow a higher-level application to “command” the helicopter using these control loops. Using this method, we hope to eventually achieve complete autonomous flight. For the scope of this project, the goal will only be to maintain an autonomous hover, which will be a starting point for future additions such as forward flight and surveillance set point flight.

A laptop computer, connected to the GPS base station is used as the base station, which will have a software interface to control the helicopter through a wireless Ethernet connection. The laptop computer collects GPS data and sends it to the helicopter computer. The helicopter also has an onboard GPS remote station, which also collects GPS data. The process of using both sets of data from the two stations is called Differential GPS, and will allow better accuracy of XYZ coordinates positioning of the helicopter. Further, an override board enables the manually controlled flight through a RC radio and enables the switch to computer control when appropriate. The computer control reads GPS data from the two GPS stations and additional information in the form of pitch (forward/backward angle), roll (left to right angle) and yaw data (compass angle) from the Precision Navigation TCM2 sensor mounted onboard the helicopter. The accumulation of positioning data will enable the computer control to compensate for deviations in coordinates, or deviations in helicopter angles through specially designed application software. Flight compensations are attained through the use of servos that provide mechanical actuation to control the aileron (affects pitch angle), elevator (affects roll angle) and collective pitch (affects height) movements on the in-flight helicopter. Another pair of servos provides the mechanical actuation to control an onboard governor, and the yaw servo that keeps the helicopter pointed in one direction by the control of an onboard gyro.

Figure 1 details the overall flow of data and control throughout the system. The sensors are read through digital ports on the computer and then use control loops to determine the proper compensation factors required to stabilize the helicopter. Compensation signals are then sent to electronic servos that physically change the appropriate onboard devices.
Design Specifications for an Automated hovering helicopter

Figure 1: System Overview
Furthermore, Figure 2 details the sub-system integration and the information flow through the processing unit. The constant flow of information from the sensors to the servo is required to maintain a robust control system.

3. Hardware

3.1 Helicopter

The development of this project is centered on an TSK Mystar 60 model helicopter. Figure 3 shows the TSK helicopter in a static position with the hardware configurations mounted and the rotor blades spread in the flight position.
The TSK Mystar 60 is a lightweight RC controlled model helicopter powered by a 2-cycle nitro-methane fueled motor, thereby, giving it a high power to weight ratio. Table 1 details the physical dimensioning and mass characteristics of the TSK Mystar 60. Its physical size conforms to the International Competition dimensional restrictions and is able to carry a sizable payload. The International Competition guidelines may be reviewed through its link on the Simon Fraser University Arial Robotics Group’s website at http://www.sfu.ca/~arg.

Table 1: TSK Mystar 60 Physical Specifications

<table>
<thead>
<tr>
<th>Engine</th>
<th>YS60-ST11 2-cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Type</td>
<td>Nitro-methane oil blend (20:1)</td>
</tr>
<tr>
<td>Weight</td>
<td>≈4.3 Kg (less fuel)</td>
</tr>
<tr>
<td>Length</td>
<td>1400 mm</td>
</tr>
<tr>
<td>Tail Rotor</td>
<td>270 mm</td>
</tr>
<tr>
<td>Main Rotor</td>
<td>1500 mm</td>
</tr>
<tr>
<td>Fuel Tank</td>
<td>Center of Gravity Location</td>
</tr>
<tr>
<td>Payload Capacity</td>
<td>≈5.0 Kg</td>
</tr>
</tbody>
</table>
3.2 Transmitter

The transmitter used to control the TSK Mystar 60 is a Futaba 8U super Series RC transmitter. Its main design features are:

- 8 channel radio system with PPM or PCM 1024 modulation
- Customizing capabilities for particular flight characteristics
- Digital trims with audible indication at neutral enables in-flight trim adjustments
- Large easy to read LCD display screen with 6 edit keys for easier programming
- Direct servo control for pre-flight testing and adjustments
- Flight timer
- Engine Cut
- Selectable Trim Rate
- Individual adjustable exponential controls

The Futaba 8U Series transmitter remote control (RC) radio is shown in Figure 4. It features 9 channels for manual control with one reserved as the mandatory completion safety override control feature. Furthermore, the first seven channels control the manual operation of the Throttle, Aileron, Elevator, Rudder and Collective Pitch servos with the other two used in control of the Governor and Gyro. The Aileron servo is for changing the roll angle of the helicopter, the elevator servo for changing the pitch angle, and the collective pitch servo for changing the vertical height of the helicopter. The Gyro is expected to keep the helicopter from a spinning rotation so that there should not be any concern about the rudder, however, only testing can verify the functionality. If the configuration is not fully functional, there may be a need to implement an additional control loop to avoid changes in yaw angle. Further, the Governor is expected to automate a constant engine speed by servo connection to the helicopter’s throttle shaft. Therefore, the focus of our automated flight will be the control of the aileron, elevator and collective pitch.
A wireless Ethernet will be used for differential GPS operations. We currently have two Ethernet modules for use in the project. The first will be integrated into our GPS base station and the other affixed into the PCMCIA slot on board the helicopter. This configuration has an excellent data transfer rate of eleven megabit per second. Further, Lucent Technologies has provided Linux drivers modules and documentations that have proved useful in system integration. Moreover, it is important that the Ethernet cards fits into pcmcia type 2 slots because our wireless Ethernet will be used in an open field. The Lucent Wavelan Orinoco PCMCIA wireless card, shown in Figure 5, is the 128-bit encryption key version wireless card. It will be used as the communication link to the helicopter to transmit data while completing in-flight missions. The Orinoco wireless card characteristics are featured in Table 2.
Table 2: Lucent Wavelan Orinoco PCMCIA Wireless Card Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Channel</td>
<td>2400-2483.5 MHz</td>
</tr>
<tr>
<td>Bit Error Rate (BER)</td>
<td>Better than 10^-5</td>
</tr>
<tr>
<td>Normal Output Power 15dbm</td>
<td>15dbm</td>
</tr>
<tr>
<td>Dimension</td>
<td>117.8 mm x 53.95mm x 8.7mm</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>0-55°C</td>
</tr>
<tr>
<td>Range</td>
<td>1750 feet/ 550meter</td>
</tr>
</tbody>
</table>

The International competition mission requires more than 3km of dependable communication range. The Lucent wireless card in Figure 5 has a shorter range, however, for the current goal of self-hovering, the shorter range should be sufficient. Further gains in communication transmission range can be realized with the use of a high gain antenna.

Figure 5: Lucent Wavelan Orinoco PCMCIA Wireless Card
3.4 Override Board

The override board is used in the wireless switching between manual and computer control modes in helicopter flight. This board allows the helicopter pilot to use manual control to do tasks such as take off or landing of the helicopter and by switching to the automated mode, allows the computer to take over control of the flight once the helicopter is in safe hovering position. This will become critical during initial flight-testing without the worry of incorrect system programming in early testing. Thereby, enabling smaller tasks goal stages to be set.

Figure 6 shows an overview of how the Override board operates. This board was designed and built by Lawrence Harris, an Aerial Robotics group member, previous to the formation of the HAWCS group. Nevertheless, this board is an integral part of the automated flight configuration and the project completion.

![Figure 6: Override board Function](image)
3.5 Sensors

3.5.1 Precision Navigation TMC2-50VR Fluid Sensor

The Precision Navigation Inc., model TMC2-50VR fluid sensor, is a small and lightweight sensor used to provide highly accurate roll, pitch, temperature, and compass heading data. It is ideally suited for use on the helicopter because of its ability to withstand vibrations and operate in a dynamic and rugged environment. It uses an advanced hard-iron calibration system, which is designed for changing environments, and the sensor module can even be programmed to auto-calibrate to better accommodate any magnetic flux or disturbances that it may encounter. The ranges and accuracy ratings of the system are shown in the table 3.

Table 3: Precision Navigation Inc. Model TMC2-50VR Fluid Sensor Characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Range</th>
<th>Accuracy</th>
<th>Resolution</th>
<th>Repeatability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heading</td>
<td>0°-359.9°</td>
<td>±5.0°</td>
<td>0.1°</td>
<td>±1.0°</td>
</tr>
<tr>
<td>Tilt</td>
<td>±50.0°</td>
<td>±2.0°</td>
<td>0.3°</td>
<td>±1.0°</td>
</tr>
</tbody>
</table>

Some of the problems associated with using the TMC are its update rate, data type limitations, and temperature sensitivity. The update rate, which will initially be tested at a preset rate of 12Hz, has a theoretical maximum limit of 40Hz. However, at this rate the data is somewhat unstable in our application. At the current 12Hz, and after internal IIR filtering, the data appears to be more stable, but more testing is still required. Further, the data limitations are due to the fact that the TMC only detects the pitch, roll, and yaw angles. The first and second order rates of change of these must be determined using difference calculations, which may result in inaccurate data. One possible solution may be the use of another sensor manufactured by Tokin, in parallel with the TMC. Moreover, temperature sensitivity, should be taken care of with the auto-calibration, but must be thoroughly tested before any automated flights.
3.5.2 Novatel GPS Sensor

The signals from a series of 24 orbiting GPS satellites (see Figure 7) and a mobile GPS module can accurately triangulate a receiver’s position. The position information can be converted to a location relative to the earth, and therefore give longitude, latitude, and height from the center of the earth. A GPS module can either be used as a standalone unit, or in combination with another unit in the form of a differential GPS system. For our purposes, we will be using a differential GPS system to obtain better accuracy for the control of the helicopter. This should allow for an accuracy of approximately $\pm 2.0$ cm in all X, Y, and Z-axis as opposed to a few meters in a standalone mode. The GPS data is expected to have an update rate of at least a few hertz, which can be modified by reconfiguring the GPS sensor unit.

However, some possible problems with GPS systems are loss of satellite signals and significant data range problems. In normal operation there are usually about 8-10 satellites “visible” to a mobile unit. But in case of bad weather or satellite malfunction this number may be reduced to only a few and may lead to inaccurate or completely invalid data. At this time, there are no solutions to this technical and environmental problem, other than invoke safety measures to ensure than the helicopter can survive significant damage and bystanders are not injured from sudden automation control loss. Design consideration are to be made by relying on several types of sensors, so that even if the GPS data is temporarily or permanently lost there should be no loss of control in the automated mode. Large data range errors are due to the limitation of the current GPS designs. Further, currently the best method to significantly reduce the data range errors is to set-up the GPS in a differential mode.
Design Specifications for an Automated hovering helicopter

3.6 Servo Control Board

The helicopter servos are controlled through the Servo Control board, which has the capability of switching between computer and manual control. This board is the common interface for handling all servos and is responsible for converting both manual and computer control into instructions for the servos. It accepts input in the form of analog pulses from the RF receiver for manual control and ASCII characters from parallel port of the computer as commands, which it must then convert to analog pulses to modify the servo positions. The computer commands will be sent to this board through a software library module that will be able to open the parallel port, send data to the port, read the status of the port, and finally close the port. The interface of this library will allow other programs to select any valid servo and set that servo to any valid angle or position. The module will then convert the servo and angle information into a format recognized by the board, including checksums and identifiers, and send this through the parallel port. The servo control software library will allow the rest of the programs to be able to treat the servos abstractly and will lead to a better modularization of the code in general.
3.7 Power Supply

Since the flight of the helicopter in the autonomous mode requires the use of sensors, servo actuators and a processing unit, a reliable power source will be required to power all of these components. Further, manual flight requires some electrical power to operate the servos that provide flight corrections. Therefore, dual DC power supplies will be used to power each of two DC voltages on the onboard systems with different grounding to prevent complete system failures and interference characteristics. Figure 8 details the Voltages and Component relationships.

![Diagram of System Power Supply]

**Figure 8: System power supply**
3.8 Component Placement

The helicopter has been configured to place its mass, in a balance proportion, on each side of the main rotor shaft, thereby placing the center of gravity as close to the main rotor shaft as possible. This configuration will enable quick corrections, not possible when large masses are placed at distances from the center of mass. Further, the component placements can be seen in Figure 9.

Figure 9: System Component Placement on Helicopter
3.9 Initial Sensor Testing

3.9.1 On-board Servos

Testing the servo functionality is be accomplished by writing a software driver for the servo control library, which will send commands to move all servos through their entire range of motion. Verification of ranges of motion is determined by measurement and observation with those values obtained trough manual control manipulation. However, some servos functionality, as in the case of the throttle, cannot be tested this manner because it compensates for in-flight engine speed maintenance. The onboard governor, and the tail rotor collective, which is controlled by the heading hold gyro, controls the throttle sensor. Whereas, the control software will manipulate the roll, pitch, and main rotor collective servos, therefore, only these servos allow for static testing.

3.9.2 Differential GPS

The GPS requires thorough testing for reliability and accuracy in a standalone mode. Following the acquisition of reasonable data from a standalone GPS module, a differential GPS system is to be configured. One GPS module will be configured as the base station and another as the mobile station. In this way most errors resulting from atmospheric interference, signal degradation and noise will affect both the mobile and base station in the same way. Then the mobile GPS module can accurately position itself relative to the base station by simply comparing the position that the base station calculates and comparing it with the position it calculates. Whereas, the differential data is all that is needed by the control system of the helicopter, to determine deviations in helicopter positioning. Further, to test that the differential data acquisition is correct, manual manipulation of the position of the mobile station by a known amount and can be verified with the resulting data acquisitions. Moreover, the data update rate can also be tested manually by measuring the number of received data structures in a specified time period.

3.9.3 Tokin Sensor

The Precision Navigation Inc. model TMC2-50VR sensor can be tested using an accurate fluid meter and protractor, or just a protractor. By manually rotating the sensor by a known amount around any one of the 3 axes, the change in angular movement is the difference in the initial angle and measured angle. These
measurements can then be used to confirm the expected accuracy values with the data produced by the TMC2-50VR sensor. Furthermore, additional tests must be performed in a variety of conditions to ensure temperature insensitivity and the correct operation of the auto-calibration feature built into the sensor. The data update rate must also be measured and modified to conform to the requirements of the designed project control algorithm.

3.10 Control System

3.10.1 Onboard Tri-M Power Controller

Batteries and a HESC 104 board converting the battery power input to the designated voltages and current requirements of the Jumptec MODS processor and the CyberOptics video acquisition boards. Figure 10 details the output characteristics and provides an image of the power converting board.

**Figure 10: The HESC 104 Power Supply Board**

The HESC104 power supply board supplies a variety of voltage to accommodate additional flexibility in the selection of hardware components that may need to be configured to accomplish automated flight in the helicopter.
3.10.2 Video Capabilities

The Video CyberOptics Imagination PXC200A color frame grabber board integrated on the helicopter computer is shown in Figure 10. This device is part of the helicopter control hardware stack. It will be used as a source of machine vision in later stages of development of forward flight stage.

Figure 11: Video CyberOptics Imagination PXC200A Color Frame Grabber

Therefore, since our current project work does not relate to this hardware, there will not be much detail provided on this device except for the information provided in Table 4. However, this device will be increasingly important when machine vision and navigation becomes a major focus of SFU aerial robotics team.

Table 4: Video CyberOptics Imagination PXC200A Color Frame Grabber Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>NTSC: 640x480</td>
</tr>
<tr>
<td></td>
<td>PAL/SECAM: 767x576</td>
</tr>
<tr>
<td>Output format</td>
<td>Color: YCrCb 4:2:2 and 4:1:RGB</td>
</tr>
<tr>
<td>Power Requirement</td>
<td>5DC, 500mA</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>0°C to 60°C</td>
</tr>
</tbody>
</table>
3.10.3 The Jumptec MOPS CD6 Processor Board

The Jumptec MOPS CD6 board is a computer fitted in the PC104 form factor. The MOPS designation in the board description stands for Minimized Open PC System. Further, in addition to receiving the output from our sensors and sending output to control the servo, our control System loops will be implemented on this control platform. Figure 12 details the board configuration with the Pentium processor clearly shown in the middle of the picture.

Figure 12: The Workhorse of the Helicopter – The Jumptec MOPS CD6 board with Intel Pentium CPU and Various Ports Identified
The computing specifications and capabilities of the Jumptec MOPS CD6 board are detailed in Table 5.

Table 5: The Jumptec MOPS CD6 Processor Board

<table>
<thead>
<tr>
<th>Memory &amp; Storage</th>
<th>Output Interface</th>
<th>Computing Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>64M SDRAM</td>
<td>1x USB output</td>
<td>Intel Pentium MMX 166 CPU</td>
</tr>
<tr>
<td>2M video ram</td>
<td>2x RS232 serial out</td>
<td>Ali Chipset</td>
</tr>
<tr>
<td>Setup</td>
<td>Ethernet</td>
<td>PCI C&amp; T Graphic Controller</td>
</tr>
<tr>
<td>2Mbyte EEPROM</td>
<td>(10/100) baseT</td>
<td></td>
</tr>
<tr>
<td>Phoenix 64M IDE flash Drive</td>
<td>CRT monitor Out</td>
<td>PowerFail</td>
</tr>
<tr>
<td>Floppy Interface</td>
<td>Parallel Port</td>
<td>Watch Dog Timer</td>
</tr>
<tr>
<td>EIDE interface</td>
<td>JIPA interface</td>
<td>PC104 &amp; PC104 plus bus</td>
</tr>
<tr>
<td>(Ultra33DMA)</td>
<td>for LCD Panel</td>
<td></td>
</tr>
</tbody>
</table>

The manufacturer has supplied operational specification that must be considered during the International competition missions and throughout the testing periods. These details are shown in Table 6.

Table 6: Jumptec MOPS CD6 Manufacturers Operational Specifications

<table>
<thead>
<tr>
<th>Physical Dimensions</th>
<th>96mm x 90mm (3.8” x 3.6”)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Humidity</td>
<td>Operation: 10% to 90%</td>
</tr>
<tr>
<td></td>
<td>Storage: 5% to 95%</td>
</tr>
<tr>
<td></td>
<td>(Under non-condensing environment)</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>5V 1.8A</td>
</tr>
<tr>
<td>Temperatures Operation</td>
<td>0°C to 60°C</td>
</tr>
<tr>
<td></td>
<td>-10°C to 85°C (Storage)</td>
</tr>
</tbody>
</table>
Design Specifications for an Automated hovering helicopter

The port configurations with output and input consideration are given in Table 7. These configurations are subject to change depending on the success in testing with the present configurations.

Table 7: Processor Board Ports with Output and Input Configurations

<table>
<thead>
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Furthermore, having a graphic controller on board is quite a blessing. The MZ104 board, which the SFU team used in 2000 competition, was plagued with problems because its lack of on board video output. If there had been the ability to see the boot messages, better diagnose of the problems could have been made and would have enabled quicker diagnosis of disk-on-chip problems.
4. Software Configurations

4.1 Operating System

The project operating system is Linux with Real Time Extension Module. Linux has the advantage of being a stable, free, open (source code available) and is widely supported on Internet. There are considerable amounts of documentation and support on the worldwide web from various private and commercial groups that can help to answer our questions and solve our problems. Further, the adherent properties make various distributions of Linux programming easily modifiable to become a compact embedded platform perfect for our application. Moreover, our group compiled a new kernel and installed the various kernel modules into the processor board. Additional drivers to enable hardware communication have written for various sensors and actuators on the helicopter computer.

4.1.1 The Kernel

We downloaded our control processor, Linux kernel source code version 2.4.9 from www.kernel.org. During the process of recompiling kernel, we made selections of the necessary components to include and exclude from our helicopter control stack. Further, we did not include unnecessary supporting options such as CD room drivers, amateur radio, ISDN, and SCSI support, while putting in event interface (used by USB), PCMCIA, wireless extension, and Ethernet support. Therefore, using this method, we can build a kernel that is small yet smart enough to support all the devices on board of the helicopter and minimize the memory space needed for processor functionality. Figure 13 is a screen capture of the selection window during kernel recompile. Unused kernel features are taken away to make the kernel smaller and more efficient.

In addition to the compiled kernel, Linux allows the so-called kernel modules to be inserted into kernel’s workspace and thus use the same resource as the kernel. The advantage is that modules can be inserted only when there is a need for that particular functionality. Whereas, most of the processor device drivers are compiled as modules, that are loaded into the kernel during boot time. Therefore, if we decided to replace a sensor, we can simply remove the module and insert a new driver into the kernel, without recompiling a new kernel.
4.1.2 The File System

Our project is using the same file system, as loaded by Ryan Sadler in the 1999 aerial robotics competition. It is custom made for an embedded system and seems to configure well with the project hardware. The procedure of loading in a new file system and a boot image of a file system are available in Ryan’s website at www.ttul.org/rrsadler.

4.1.3 Real Time Extension Support

The kernel module used in the project will give us the ability to create our control program without the worry of context switching and blocking problems that can hinder a real-time system’s performance. Further, the project module will used from one of the project sponsoring companies, Lineo. However, without proper benchmarking and field test, we will leave our options open to change, since there are quite a few varieties of Linux real-time programming platforms available.
4.2 Control Modeling

The control model consists of five control loops, the pitch angle of the helicopter (circular path of rotor blades), the roll angle, the latitude position, longitude position and vertical position. These control loops have been designed to be implemented as shown in the Figure 14. In the control loop, we assumed that the helicopter fuselage to be parallel to the disk (circular path of the rotor blades) to make the model simpler.

![Control Model Overview](image)

**Figure 14: Control Model Overview**
4.3 PID Looping

In Converting Simulink Block Diagram to C program, we have to remodel the system, by replacing the continuous state elements to fixed-step elements. For example, the transfer functions are changed from the Laplace to the z domain.

From within Simulink, under the Tools menu, we can run Real-Time Workshop to convert the simulation model into C code. The C code produced with commenting the same as our model file, so we can easily find the points in the program we wish to augment with our sensor code. Further, we need to set the step times to small increment to ensure that an accurate operating model is produced.

However, if the code produced from Real-time Workshop does not compile, or does not run correctly, we will try writing the code from scratch. In this case, there will be a need to pass 12 numerical constants (for the 4 PID control loops) to the program. Consequently, numerical integration and differentiation will be required to be integrated into the operating program. Therefore, it may be necessary to experiment with Euler methods using a small step size and test if the required accuracy is produced.

4.4 Simulation

Simulink may be used to simulate the control loops interacting independently to one another. The simulations will allow us to estimate the effect of using a PID loop, and also estimate values for the PID constants. Our implementation plan is to insert disturbances such as wind and make observations to see if the control model can make adequate compensations. A screen shot of the Simulink window is shown in Figure 15.
4.5 Device Drivers

Some of the device drivers integrated into the project are commercially available, however, some have had to be written by our team to utilize hardware configurations in the project.

4.5.1 TCM2 Fluid Sensor Driver

A Hawcs team member, Shahin Raboubi, wrote this device driver. The driver is a serial port driver, which periodically reads the TCM2 data. The acquired data contains roll, pitch and yaw information used in the control program to maintain constant positioning. Further, ambient temperature values are transferred, which can be used to calibrate the sensor for better output.
4.5.2 Tokin USB 3D Sensor Driver

A senior SFU ARG member, Ryan Sadler, has written this device driver during summer of 2001. However, there have been difficulties in USB port programming and difficulties in obtaining useful and meaningful data, thereby making the use of this driver in doubt at this stage of development. Therefore, we will not fully exploit the Tokin sensor functionality until later development stages. Moreover, we will only be using the USB sensor for acceleration.

4.5.3 Override Board Drivers

HAWCS members, Shahin Raboubi and Michael Adachi, wrote this driver. It is parallel port driver and communicates angle-positioning data through a parallel port that connects to the override board. This driver allows us to control the servomotors, which changes pitch angles of helicopter blades through linkages.

4.5.4 Tokin Sensor Drivers

The Tokin TMC fluid sensor will be controlled through a software driver that will access the sensor through a COM port. When the driver is activated is will first calibrate the sensor by sending a sequence of commands through the port. This will insure accurate results given the dynamic operating conditions. After set-up, the software will constantly read the sensor data at a specified rate and write this data in the form of a sequence of 32-bit elements in a specified location of shared memory. This information can then be read by a higher-level application such as the control software.

4.5.5 Novatel GPS Drivers

A Hawcs team member, Jimmy Tsai, wrote this serial port device driver. Although written as a serial port driver, a portion of the driver transmits GPS differential data though a UDP protocol. By using differential correction data, we hope to achieve high enough accuracy to give meaningful elevation data. However, this will be dependant on good weather and availability of open spaces during operational testing and missions. Most importantly, once we enter the forward flight stage, we will require the Novatel GPS to transmit position coordinate using the GPS technology.
4.5.6 Intel Ether Express 100 Ethernet Driver

This is a commercially available Driver that is provided with the hardware at the time of purchase. The installation of these drivers is relatively less troublesome because they are provided from REDHAT Linux distribution. However, we are still required to change different configuration files and scripts to install them.

4.5.7 Lucent Orinoco Wireless Ethernet Card Driver

This is another commercially available Driver with update available on the manufacturer’s website with REDHAT Linux distribution also available. The use of this driver has provided a shorter development time.

5. Testing

5.1 Table Testing

The table testing will allow us to test the pitch and roll angle control models indoors. This will be especially important on rainy days, where the GPS will not be operable. Our initial demo will be on the test table, which will allow us to test whether the servos move to compensate for changes in helicopter angles. We expect the table testing to be operational before we do any flight-testing. Table testing will allow us to observe affects of adjusting the control model constants and observe the functionality of the user interface with the helicopter computer. After the pitch and roll angle control models are tested, we will want to test the latitude and longitude control models outside with the GPS system. We will want to make sure the servos compensate for changes in these directions properly. Finally, the vertical direction will be tested to make sure that the helicopter computer recognizes changes in vertical position and compensate for it. We want to make sure all control models are working before moving onto more critical testing.

The system testing can be accomplished in a static method on a specially designed tilting table. The table has been established to tilt and roll by the manipulation of several planes (as seen in Figure 16). Therefore, the table enables testing of tilt and roll compensations (see Figures 17 and 18) made by the processing unit and translated through servo movements.
Design Specifications for an Automated hovering helicopter

Figure 16: Multi-plane Testing Table

Figure 17: Multi-plane Testing Table in a Back Tilt Configuration
Design Specifications for an Automated hovering helicopter

Figure 18: Multi-plane Testing Table in a Forward Tilt Configuration

Figure 19: Multi-plane Testing Table in a Forward Roll Tilt Configuration
5.2 Flight Testing

Once the table testing is complete, the next stage of development is to proceed to actual flight-testing. Since we have a very expensive piece of equipment that could be damaged, when testing our control system, we will need the services of a very experienced model helicopter pilot to manually control other non-automated variables while each PID loop is tested. Moreover, we need the skilled pilot that is able to make a fast recovery in case of an unexpected failure in our control design.

In flight-testing, the servo controls will be isolated so each control loop can be tuned individually. We may have to decrease the gains calculated in the simulations because when in flight, having smooth gradual changes is better than quick jerky motions. Further, initially each PID loop assumes all other parameters outside its own are constants. If this approximation is not accurate enough to achieve a stable hover, the model will have to be improved to add more detail.

The order we will test the control loops is as follows:
1. Roll
2. Pitch
3. Height
4. Longitude
5. Latitude
6. Yaw (if necessary)

Furthermore, the roll and pitch should be easier to test, since those two variables were already had extensive testing on the static test table.

5.3 Wireless Testing

Since the Lucent Orinoco Cards will be used for differential data and telemetry data transfer, we need to verify its performance and reliability. Moreover, the significance of these tests becomes more important as the project progresses from hovering to forward flight, and especially from open area testing to actual mission flight.
5.3.1 Reliability Testing

By checking the wireless utility (Linux command "iwconfig", "iwpriv", "iwspy") on our base station laptop, we can have a statistics of numbers of byes sent, number of byes received. Most importantly, we can also get numbers of packets lost and the collision rates. From these statistics, we can know how reliable our wireless link is transmitting.

5.3.2 Range Testing

We plan do a field test with both the wireless Ethernet and GPS. The screen of our base station will print the available data and actual will determine reliable operating ranges of the Ethernet. Even if the communication distances are not as required for competition missions, our project group should be able to use the existing configuration for the automated hovering helicopter. Nevertheless, the grounds of SFU are an excellent place to test for electromagnetic interference due to the BC Hydro communication tower at the top of the hill. If our testing shows an acceptable signal reception, there is a significant possibility that any other testing or competition place will not pose a problem to our wireless link.

5.3.3 Vibration, Noise, and Contamination

This is the issue that our group is most worried about. Since the rotor blades of our helicopter will rotate at 1500 rpm, there will be constant vibration and noise coming out from the rotor head and gasoline engine. Whereas, the actual flight test might be the only way to know how well this problem downgrades the wireless performance. Further, the muffler on the helicopter will constantly output exhaust gases and unburned lubrication oils during the flight, therefore, we are concerned about particulates in the air adversely effecting the wireless Ethernet performance. Fortunately, we will have experienced RC helicopter pilots that are willing to help us. The override system setup will enable these pilots to switch to manual control at the sign of first problem to alleviate any possible equipment damage.
6. Future Developments

6.1 Forward Flight

After HAWCS corp. achieves the ability to hover autonomously, members of the HAWCS corp. and the rest of the SFU Aerial Robotics Team will use the result of the project as a basis for more sophisticated flight capability – most importantly the transition from hovering to forward flight. Since the scheduled timeline for hovering is December 2001 and the next aerial robotic competition is schedule in July 2002, six addition months will be available for future development. New modeling, control system tuning parameters and even new hardware will possibly be applied.

6.2 New Override Board

Currently, the development HAWCS corp. will be based on the initial Servo Override board, developed for year 2000 International Arial Robotics competition. An improved version of the board is currently under development by Lawrence Harris, as a member of the SFU Aerial Robotics Group. The new board performs the same functionality as the old board; however, it has the addition capability of reading the input to the servos. This additional function is significant because we will than able to read a helicopter pilot's input and apply Ziegler-Nichols tuning on our PID regulators.

6.3 Tokin Sensor

Initially, we were interested in using the Tokin sensor as our only motion sensor input. This sensor is more versatile because it has three gyros, one compass, and two accelerometers. From the data provided by its accelerometers, our group can have a better idea of the movement and corrections of our automated helicopter. However, the company did not provide a Linux USB device driver. The software performing this task is being written by another of SFU ARG member, Ryan Sadler. Although, its was started during summer of 2001, the software will not be ready for a mission critical task at this time. We are confident that given adequate development time, the new software will allow our group to take advantage of the Tokin sensor's addition functionality over the TCM2 sensor in the present hardware configuration.
6.4 Competition Mission

Autonomous flying is just a part of the aerial robotic competition. The goal of the mission encompasses several scenarios (see Appendix 1, 2 and 3). Most of them require vision processing and artificial intelligence. For example, one of the scenarios is a reconnaissance mission that requires autonomously flying 3 km toward a house, enter the house through a one by one meter window, navigate inside the rooms to take pictures and transmit those pictures back into remote station. The completion of this and others tasks described in the Appendixes will remain a challenge and the focus for the SFU Arial Robotics group in the coming months.

6.5 Telemetry Display

We need to configure a system that would enable a display of sensor data to be transferred and displayed onto a laptop while the helicopter is flying. It will become an essential diagnostic tool for the group to verify and improve the control algorithm. It will ultimately display the sensor input, current servo output, and control state variable output.

7. Conclusion

An autonomous aerial robot has a significant advantage in large-scale search, police surveillance, and rescue missions. As the robotics technology advances, autonomous robots will be capable of doing much more. The SFU aerial robotics group and its helicopter division have dedicated themselves to the progress of such technology.

After a year of hard work on hardware, the SFU ARG’s modified RC helicopter currently has the architecture and the computing power of an autonomous aerial robot; however, it still needs the control system software and rigorous refinement of system integration before we can accomplish autonomous hovering.

Team HAWCS© has made creating and installing a control system, the heart and soul of the ARG helicopter, as its central mission. Further, as members of this team, we have the knowledge, experience, and resources to successfully complete this project and subsequently capture the International Aerial Robotics title in the upcoming 2002 competition.

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MISSION EXAMPLE No. 1 — Hostage Rescue

Darkness is upon the face of the deep as a breeze moves silently over the surface of the waters. Suddenly a periscope is thrust through the still boundary that divides the waters from heavens. Low on the horizon are the twinkling lights of a coastal city. In that city lies an embassy in which the diplomatic staff is being detained by a terrorist group known as the "Independent Anarchist Rebel Coalition".

The periscope scans the dark surface for vessels— none are detected. Soon, the Spesialkommando Elite Assault League 6 (SEAL-6) will deploy from the submarine to take control of the embassy and free the hostages. First however, an aerial sensor probe will be launched from the submarine to determine how many terrorists are guarding the hostages.

The submarine lies three kilometers from the city in deep water. The embassy is near the waterfront and is identifiable by two great lights illuminating the national seal (see Figure 20) over the main entrance which is an image in the likeness of a circle with a cross at the center. Because this incident is occurring in a tropical third world nation, the embassy will have some of its windows open to the evening air.

Your mission is to have an autonomous aerial robot carry sensors from the location of the submarine to the embassy, and then covertly enter the embassy to provide a picture of the hostages and their captors that can be viewed back on the submarine. This information must be obtained as quickly as possible so that SEAL-6 will know the location and size of the threat before a rescue attempt is made. The reconnaissance mission must be completed within 15 minutes of launch from the submarine in order to maintain the element of surprise.
Figure 20: Periscope View
MISSION EXAMPLE No. 2 — Nuclear Disaster

April 26, 1:23:44 hrs Greenwich mean time. Let there be light: and there was light. A great fire ball illuminates the night followed seconds later by the sound of a thunderous explosion. A catastrophe of unknown cause or extent has occurred in Unit #4 of the Ukrainistan nuclear reactor complex. All that is seen now is the dull red glow of burning graphite from the KMBR-1000 reactor.

There are no survivors within the facility. Radioactive elements of Iodine-131, Cesium-137, and Strontium-90 are present in lethal levels. A safe distance for human investigative teams has been determined to be no closer than three kilometers. Units #1 and #3 have apparently shut down automatically, but Unit #2 is still operating, possibly due to a fault in the control system that makes the emergency shutdown unable to function. Long distance aerial photography indicates that the overpressure from the explosion has blown out all windows in the facility.

Your mission is to have an autonomous aerial robot carry sensors from a safe location (three kilometers distant from the complex) to the control room of Unit #2 which is identifiable by two great lights illuminating the Ukrainistani National Seal (see Figure 21) over the main entrance. The seal is an image in the likeness of crossed swords within a circle. Sensors must enter the control room to provide a picture of the main control panel gauges and switch positions so experts can see why Unit #2 has not shut down and assess the potential for a meltdown of this unit. The reconnaissance mission must be completed within 15 minutes of launch from the three kilometer safety perimeter due to expected radiation-induced failures within the aerial robot’s systems.
Figure 21: Nuclear Disaster
MISSION EXAMPLE No. 3 — Biological Emergency

During archaeological excavations near Athena Greco, a necropolis dating back to 425 BC was discovered containing seven mausoleums. Each mausoleum consisted of several catacomb-like chambers. Only two of the mausoleum buildings remain intact. Soon after the discovery, the archaeologists fell ill, at first with strong fevers accompanied by redness and burning of the eyes, followed by vomiting of blood. Within one hour, victims' skin became severely ulcerated and bleeding was observed from all openings of the body. No personnel having direct contact with the site have survived longer than 4 hours.

A team from the CDZ and the US Army Medical Research Academy for Infectious Disease (USAMRAID) set up a field laboratory where they determined the cause of the epidemic to be a new strain of the Ebola virus. Dr. Jackson Gilbertman of the CDZ in Atlanta has reported that this is the most lethal strain of the virus investigated to date. In an interview earlier this week, Dr. Gilbertman stated that, "This is not really a new mutated strain of Ebola, but most likely an ancient strain that has been locked away in the Athenan tombs for almost twenty five hundred years."

What is most disconcerting, is the finding that this "new" (ancient) strain, dubbed "Ebola-A425", exhibits increasing evidence for possible airborne transmission. According to Dr. Gilbertman, "Researchers from USAMRAID have done formal aerosol experiments in which as little as 400 plague-forming units of Ebola-A425 caused a fatal disease in monkeys within four to five hours. All exposed monkeys developed Ebola-related pneumonia, and virus particles were found in many different areas of the respiratory system." No one who entered the mausoleum chambers remains alive. A three kilometer quarantine radius around the site has been ordered by the government. In order to contain the outbreak, no one is allowed to enter or leave this perimeter. National Guard units from the Greco Ministry of Defense have been sent to the quarantine zone to suppress rioting that is on-going in the villages of Phaetalos and Necros which reside just inside the perimeter.
Figure 22: Biological Emergency Setting
11. References


Novatel GPS Millennium GPS card Command Description manual
Software Version 4.45


