# Design and Implementation of an Indoor Aerial Robot

Geoff Hollinger, Alex Flurie, and Zach Pezzementi
Swarthmore College Engineering

Engineering 90 – Senior Design Project
Advisor: Dr. Bruce Maxwell
Project Proposal Submitted: November 19, 2004

**Abstract**

An aerial robot will be designed and constructed for participating in an aerial robot competition. The choice of parts for construction will be informed by, but not limited to, equipment recommended by the organizers of the competition. The robot will be designed to operate under autonomous or manual control, and will incorporate features such as control mechanisms for autonomous flying, vertical stabilization, and gust stabilization and vision systems such as visual odometry and obstacle avoidance. The goal of the project is to win the competition and aid the organizers in developing a standard package which competitors may purchase for the competition.

## Introduction

In the spring of 2005, Drexel University will host the first Annual Indoor Aerial Robot competition, inviting all of the colleges in the Philadelphia area to submit entries. The objective of the competition is to explore the potential of aerial robots for the task of search and rescue, both in terms of their benefits and of their challenges. Each team is suggested to consist of four undergraduate students with one faculty advisor; Swarthmore's team will have only three students. The robots built for the competition will consist of a blimp with motors and fans for propulsion, camera and sonar systems for sensing and navigation, control systems for gust stabilization, and any other additions that contestants deem useful. The competition course will be a basketball gymnasium divided into three parts with different challenges: autonomous control, human control, and tele-operated control.

In the autonomous control section, the robot will have to navigate a simple maze without any outside input. Points will be awarded on the basis of how far the robot is able to travel through the course and how well it is able to avoid collisions. The task is simplified by the placement of a black line of tape on a white floor denoting a "collision-free" path. A successful line-following algorithm must be developed to navigate this portion of the course. A ramp will also be placed in an unknown position towards the end of the course that the robot will need to ascend, demonstrating autonomous terrain-following. The final challenge of the autonomous section is a low-speed fan, meant to simulate wind disturbances, which will require an effective gust stabilization system.

Next, in the human control section, the robot will navigate an obstacle course in full view of its human operators. The operators will be able to use the robot's sensory information as well as their own to clear these obstacles. Points will be subtracted here for every collision with a wall.

Finally, the tele-operated section consists of a simulated search-and-rescue situation. In this section, the robot is still controlled by human operators, but they can no longer see the robot, and must therefore rely entirely on the information the robot transmits for information about the robot and its environment. Several "victims" will be scattered about this portion of the gym and the objective will be for the robot to drop markers as close as possible to each victim. Points will be awarded based on how close the marker is to the victim, scaling down linearly to zero at a distance of three feet.

The remainder of this report describes how a submission to this competition will be designed and implemented. First, a technical discussion of each of the component parts and their integration is presented. Next, a project plan is laid out with estimated time requirements for each task incorporated into a CPM diagram and timeline. A description of the qualifications of each group member and his necessity to the project follows, with manpower and resource requirements broken down by task. The final section tallies the cost of the project by task and provides a list of the necessary materials.

## Technical Discussion

The blimp will be Plantraco's Tri-Turbofan model. It includes a payload to which two stationary motors are molded. It includes an RF transmitter for human control.

The central controller on the side of the robot will be the OOPic-R. [1] This controller is designed especially for robot control; it has two PWM lines for speed control on motors, four lines for servo control, and other lines for obtaining sensor data. There are multiple power options available on the board, which allows the freedom to try different batteries and battery types. If the freedom of movement given by the blimp kit's motor is not sufficient or a way to control the motors from the Pic cannot be determined, two gear-driven motors will be purchased that will be mounted to the payload. It is expected that the visual odometry will allow for path sensing and control in yaw, so one of the digital channels will be used to control a servo for each motor that will give it freedom of rotation in the plane parallel to the floor. A third motor may be employed on the top or bottom of the basket that would allow for vertical stabilization; if the motor is on the top, we will simply use it to counteract buoyancy for a loss in payload by providing a downward force; if the motor is on the bottom, we will maintain the balloon at less than neutral buoyancy so that we may reduce the speed of the motor when we lose mass.

For the blimp's sonar systems, three Polaroid SensComp sonar packages will be placed on the front of the blimp [3]. This type of sonar sends a ping of 16 high-to-low ultrasonic transitions between +200V and –200V with a frequency of 50 kHz. The ping then spreads radially from the sonar transducer and reflects off obstacles. Upon hitting the transducer, the ping creates a voltage, which is then fed to an amplifier and output on the ECHO line. The ideal object range for these sonar packages are from 2 to 35 feet. This is within the range needed for our aerial blimp applications.

The Polaroid SensComp is also ideal for interfacing with PIC chips such as the one that will be used on the aerial robot. The only required connections are the ECHO and INIT line to send and receive signals from the sonar. In addition, the sonar requires a very low 100 mA current in standby mode, so it should not draw large amounts of power from the mechanical and vision systems.

To reduce sonar noise, a salt-and-pepper filter will be implemented, followed by a Kalman filter stage, and a weighted average of the three sonar packages will be used. To further increase the reliability of our sonar, a noise elimination algorithm will be implemented as described in Reference [2]. This method seeks to time the ultrasonic bursts between sonar packages to eliminate crosstalk and minimize environmental noise. This sonar implementation should allow the aerial robot to navigate the light-absorbing wall in the final competition.

The blimp's vision system will be provided by one of two wireless cameras, the Eyecam from RCtoys or the Micro-Miniature Wireless B/W Pinhole Camera from The Spy Store. Both cameras transmit at 2.4GHz with auto gain and white balance, in NTSC format, though the Eyecam also offers the option of PAL format. The Eyecam claims a longer transmission range, 1000' compared to 700' line-of-sight. The Eyecam also specifies a weight of only 9 grams, while the Spy Store camera does not provide one, which will be an important factor on a blimp. The Spy Store camera does, however, sell compatible rechargeable batteries for their camera as well, while the Eyecam does not provide information on batteries for price comparison. Both cameras transmit to a receiver which will connect to a personal computer to provide digital images via a frame-grabber already available in the Engineering department. This image will then be used for video processing and display.

Regardless of the camera used, it will serve three main purposes. The camera will be the primary interface for the tele-operated portion of the course. The use of a color camera would significantly increase ease of use for this task. The second function of the camera, visual odometry, will be important for all parts of the course. The third function, visual servoing, will be the primary means of navigation in the autonomous section.

Visual odometry is used to determine ego-motion from successive frames of video. The process consists of finding "interesting points" in each image, usually with something like a Harris corner detector [4], then finding the correspondence of as many points as possible between the two estimates. This correspondence provides a stereo pair of views of the same scene, and the difference between the two positions can be computed by geometry. A large number of points returned by the corner detector improves the accuracy and confidence of motion estimates but also greatly increases computation time. It may therefore be necessary to control the sensitivity of the corner detector to get a useable frame rate, probably with a Kalman filter.

Visual servoing will be used for line-following in the autonomous section. It consists essentially of finding the line in the image, determining where it is in relation to the center of the image or the blimp's path, and then sending the appropriate motion commands to keep the line in the center of the image.

This project is significant because it is a model Swarthmore Senior Design project for two reasons: it is a truly interdisciplinary endeavor, and it is based heavily on the analysis and control of physical systems. The project incorporates fluid systems, digital communication, microcontroller programming, digital processing, electrical design, and physical design. The physical analysis and control are apparent in the vision processing necessary to chart courses, the feedback loops used to maintain these courses, and the vertical and gust stabilization systems.

## Project Plan

To accomplish this project, it is necessary to purchase, implement, and integrate all of the systems on the aerial robot. These systems include sonar, camera vision, and motor control. The first task will be to order the blimp, helium, and simple motor supplies from a vendor. Once this purchase is complete, it will be necessary to assemble this blimp. During the assembly process, cameras and vision equipment should be ordered to allow for timely integration with the aerial robot. Once the vision system is added to the blimp, it will be necessary to design and implement the vision control as described in the section above. Also, the sonar system must be ordered from the vendor and integrated with the blimp.

The most critical tasks for designing the blimp will involve the design of the motor and buoyancy controls. It is expected that these controls will be implemented using a PCB board. Before the PCB board can be designed and ordered, a FPGA prototype of the control must be implemented in VHDL and tested on the blimp. Once the vision, sonar, motor, and buoyancy controls are integrated into the aerial robot, it is expected that two more weeks of testing and final troubleshooting will be necessary. Figure 1 gives a summary of the necessary tasks along with their dependencies, durations, and the effort required to complete them.

| Activity | Needs | Feeds | Duration | Effort | Action |
|---|---|---|---|---|---|
| A | - | B | 2 wks | 6 hrs | Order blimp and simple motor supplies |
| B | A | D,G,K | 1 wk | 18 hrs | Put together simple prototype blimp |
| C | - | D | 2 wks | 6 hrs | Order camera and vision equipment |
| D | B,C | E | 1 wk | 18 hrs | Add vision system to prototype blimp |
| E | D | O | 6 wks | 10 hrs | Design and implement autonomous vision control |
| F | - | G | 2 wks | 6 hrs | Order advanced motor and buoyancy equipment |
| G | B,F | H | 1 wk | 18 hrs | Add motor and buoyancy equipment to blimp |
| H | G | I | 4 wks | 10 hrs | Implement FPGA motor and buoyancy control |
| I | H | M | 1 wk | 10 hrs | Design PCB for motor and buoyancy control |
| J | - | K | 2 wks | 6 hrs | Order sonar equipment and interface |
| K | B,J | L | 1 wk | 10 hrs | Add sonar to blimp |
| L | K | O | 5 wks | 10 hrs | Design and implement autonomous sonar control |
| M | I | N | 2 wks | 6 hrs | Order PCB for motor and buoyancy control |
| N | M | O | 1 wk | 6 hrs | Add PCB to blimp for final motor and buoyancy control |
| O | E,N,L | - | 4 wks | 8 hrs | Integrate vision, sonar, motor, and buoyancy systems, write report |

Figure 1: Network specification and activity description for aerial robot design

From the information described above, a critical path method was designed to examine the project dependencies for this project.  Figure 2 confirms that the motor and buoyancy controls form the critical path for this project, and their timely design and implementation should be insured throughout the design process.  It was also determined that there are several extra weeks available to design the vision and sonar systems.

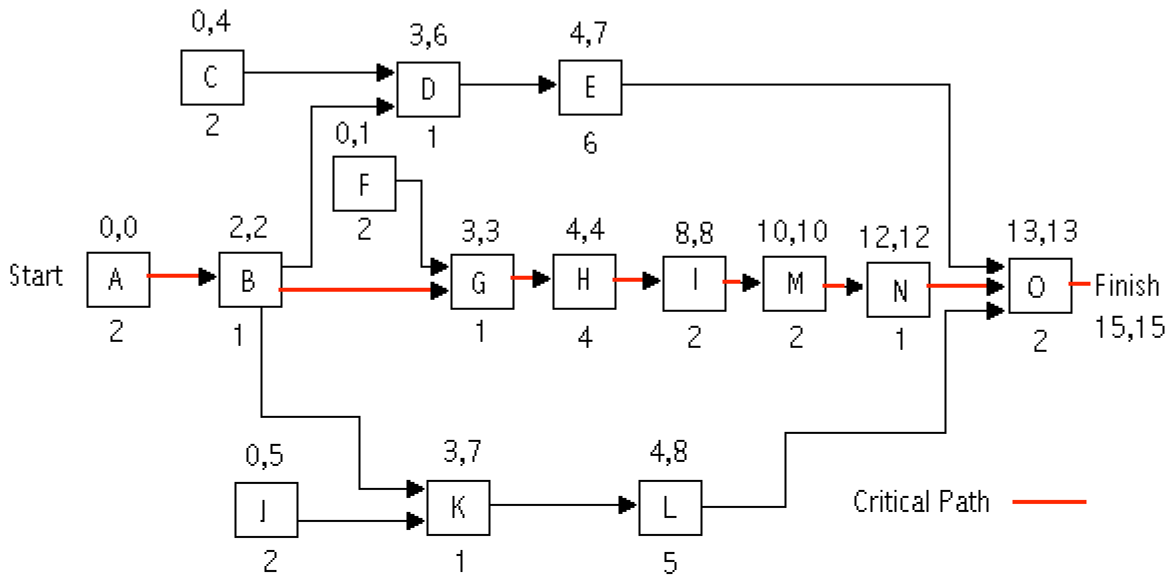


Figure 2: Critical path method for aerial robot construction

Using the critical path analysis, a time line was developed to visualize the project time budgeting. Figure 5 shows this timeline and shows that most work on the project must be done during the middle weeks. The timeline also confirms the necessity to ensure timely completion of the motor and buoyancy controls.

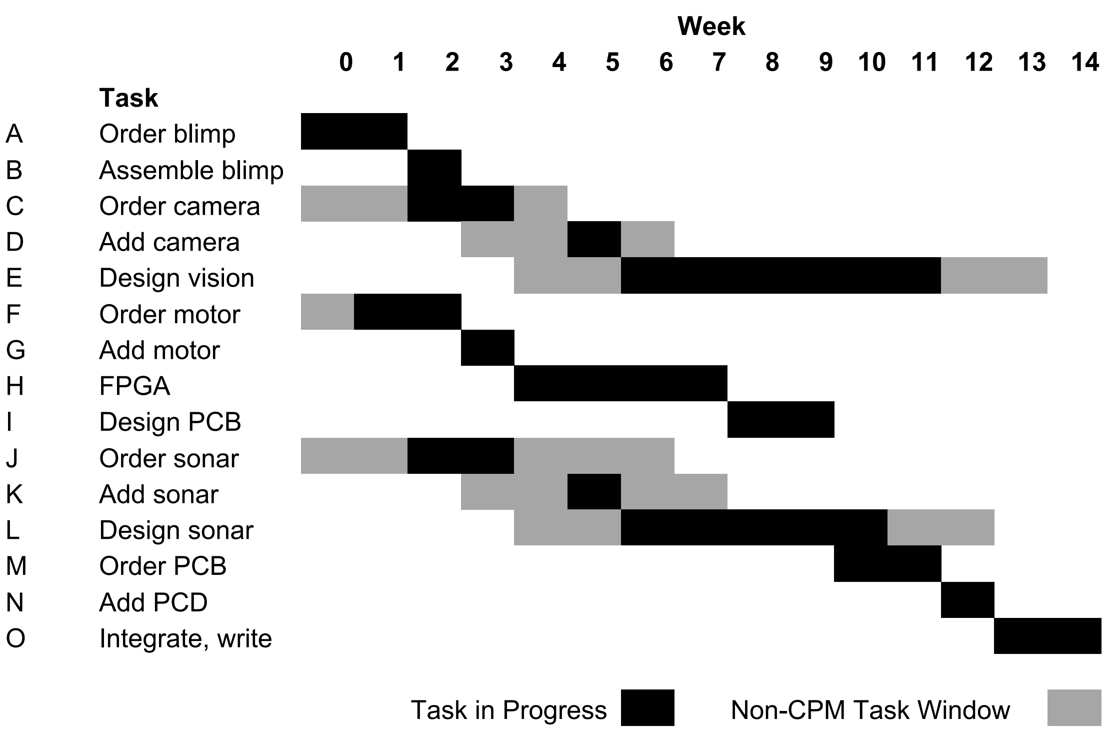

Figure 5: Timeline of task completion

To further examine the time constraints on this project, a project time budgeting table was made. Figure 3 gives the estimated work hours per week from late November until mid April as 332 hours. This project currently has three engineers capable of working up to ten hours a week. The time budgeting table shows that the project can be completed using these human resources in fifteen weeks.

This project will have three tiers of completion signifying projects of further and more sophisticated development. The first tier will be achieved when the robot hardware is fully integrated and controllable by a joystick input. The second tier will be achieved when the development of the software for vision, control, and movement that allows autonomous navigation is complete. The third tier will be achieved with the successful operation of these systems in concert that allow the robot to place in the competition.

| Week | Activites in Progress | Activity Hours | Total Week's Hrs | Total Project Hrs |
|---|---|---|---|---|
| 29-Nov | A,[C],[F],[J] | 6,0-6,0-6,0-6 | 6 to 24 | |
| 6-Dec | A,[C],[F],[J] | 6,0-6,0-6,0-6 | 6 to 24 | 12 |
| 13-Dec | B,[C],[F],[J] | 18,0-6,0-6,0-6 | 18 to 36 | 54 |
| 10-Jan | [C],[D],G,[J],[K] | 0-6,0-18,18,0-10 | 18 to 52 | 72 |
| 17-Jan | [C],[D],[E],H,[J],[K],[L] | 0-6,0-18,0-10,10,0-10,0-10 | 10 to 64 | |
| 24-Jan | [C],[D],[E],H,[J],[K],[L] | 0-6,0-18,0-10,10,0-10,0-10 | 10 to 64 | 84 |
| 31-Jan | [D],[E],H,[J],[K],[L] | 0-18,0-10,10,0-10,0-10 | 10 to 58 | 102 |
| 7-Feb | [E],H,[K],[L] | 0-10,10,0-10,0-10 | 10 to 40 | 152 |
| 14-Feb | [E],I,[L] | 0-10,10,0-10 | 10 to 30 | |
| 21-Feb | [E],I,[L] | 0-10,10,0-10 | 10 to 30 | 172 |
| 14-Mar | [E],M,[L] | 0-10,6,0-10 | 6 to 26 | |
| 21-Mar | [E],M,[L] | 0-10,6,0-10 | 6 to 26 | 184 |
| 28-Mar | [E],N,[L] | 0-10,6,0-10 | 6 to 26 | 300 |
| 4-Apr | O | 16 | 16 | |
| 11-Apr | O | 16 | 16 | 332 |
| 18-Apr | Done | | | |

Figure 3: Project time budgeting by week

## Project Qualifications

The resources and facilities at Swarthmore College are more than adequate for successful completion of this project. Many of the robotic and computer vision supplies are already available in the Hicks Engineering Building, and the Hicks Mural Room has sufficient space and computing facilities to act as a test site for aerial robot testing. The Papazian Machine Shop also provides the necessary facilities for material processing and chassis construction. For this project, the main researchers consist of three undergraduate engineers capable of working ten hours a week for the duration of the project. In addition, the team will also benefit from the assistance of Grant Smith, a machinist, and Ed Jaoudi, an electrical technician.

The main researchers, Geoff Hollinger, Alex Flurie, and Zach Pezzementi have the necessary background to complete this project. Geoff has done coursework in control theory, computer vision, and electrical circuit design. He has also completed two summers of independent research in the fields of computer vision and robotics. Zach has completed several computer science classes as well as coursework in digital systems, control theory, computer vision and perception, and thermodynamics and fluid mechanics. He has also completed two summers of computer vision research. Alex has completed coursework in control theory, computer architecture, and electrical circuit design. He has completed a summer of research in underwater signal processing and system development and a summer of research in PCB development for multiple microprocessors.

## Project Cost

The major cost for this project comes from buying the necessary materials for the aerial robot. These materials include blimp chassis, vision equipment, sonar equipment, a PIC micro-controller, motors, and servos. The list below gives an account of the materials necessary to construct the aerial robot as well as web sites from which they can be ordered. The total project cost ranges from $584-$865 depending on the quality of the components.

**Required Materials**

Blimp and Remote Controls: $78

Replacement Blimp Balloons (2): 2 x $12 = $24

http://www.plantraco.com/product_tri.html

Helium: $25

http://www.orientaltrading.com/otcweb/application?sku=17/91&prefix=IN

SensComp 600 Sonar Package (3): 3 x $57 = $161

http://www.acroname.com/robotics/parts/R135-SONAR4.html

Associated batteries: ?

OOPic-R $89

**A-List Materials**

Color CMOS 2.4 GHz Wireless Camera: $250

http://www.rctoys.com/eyecam.php

6V 19:1 Gearmotor with encoder 2 x $119 = $238

http://www.acroname.com/robotics/parts/R179-6V-ENC-MOTOR.html

Associated batteries: ?

**B-List Materials**

Heavier and Noisier Wireless Camera: $150

Associated battery and charger: $29

http://www.thespystore.com/wirelessvideo.htm

Surplus 6-12V Gearmotor 3x $9.50 = $28.50

http://www.acroname.com/robotics/parts/S5-GMOT-4.html

## References

[1] "OOPic-R Specs" <http://www.oopic.com/oopicr.html>

[2] Borenstine, Johann. "Error Eliminating Rapid Ultrasonic Firing." University of Michigan: 1996. <http://www-personal.engin.umich.edu/~johannb/eeruf.htm>

[3] "Polaroid/Senscomp Sonar Ranging Primer." Acroname Robotics Articles. Nov 4, 2004. <http://www.acroname.com/robotics/info/articles/sonar/sonar.html#s3>

[4] C.J. Harris and M. Stephens. A combined corner and edge detector. In *Proceedings of 4th Alvey Vision Conference*, pages 147{151, Manchester, 1988.