Omni-Directional Vision System for Mobile Robots

Proposal for Research

Presented to Professor Ricardo Gutierrez-Osuna
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by
The A Team

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Introduction

The A Team proposes the development of an omni-directional vision system for mobile robot navigation. We will deliver a mobile robot equipped with an imaging system consisting of an omni-directional mirror and a small video camera. The robot will also be outfitted with an obstacle detection and avoidance system to prevent collisions.

The primary goal of our project (Phase I) will be the implementation of a video tracking system to induce our robot to follow a desired target object. The robot will "lock on" to a brightly colored object which it will then pursue. The robot will move towards the target, constantly monitoring the target's position, and if the robot "catches" the target, the robot will stop a specified distance from the target. The robot should move without colliding with walls or other obstacles in its path.

We have two options for an expansion phase for our project (Phase II) should time, budget, and expertise allow us to pursue additional complexity in our system.

1. *Interaction of two robot systems in a gaming manner such as tag*

   This option would require the purchase and fabrication of a second robot and omni-directional imaging system, after which we could program one robot to "chase" the other one. The original Phase I robot would "lock on" the new robot and follow it. The Phase II robot would be programmed to move in the opposite direction from its given target, and thus the robots would engage in a game of tag. Constraints would be enforced so that the robots would not actually collide with one another, but instead the game would be over when the chasing robot gets within a specified distance of its target robot.

2. *Remote robotic control system utilizing a live video feed to allow an individual to steer the robot in any desired direction*

This option would allow for a second operational mode to implemented on the original robot system. A switch or other method for choosing between operating modes would be added. The original Phase I tracking would be one of the operating modes, and we would develop an alternative operating mode which would allow a computer user to control the movements of the robot remotely. The omni-directional image acquired by the robot would be transmitted back to the computer and unfolded for panoramic viewing. The user could then see the exact location of the robot and its surroundings, and he could simply click on a region of the robot's view to tell the robot to go in that direction. We would implement an algorithm to convert the coordinates on the user's view into a format where we could tell the robot to move in the specified direction.

Background Information

Omni-directional vision is the ability to see in all directions from a given center. Rather than using a traditional camera to scan 360 degrees or using several cameras to gain a 360 degree view, many researchers are now using a standard video camera pointed upwards at a convex mirror. The resulting view can be used in its raw form, or it may be unwarped or reprojected onto a cylindrical surface by mapping its spherical coordinates to cylindrical coordinates (see Figure 1).

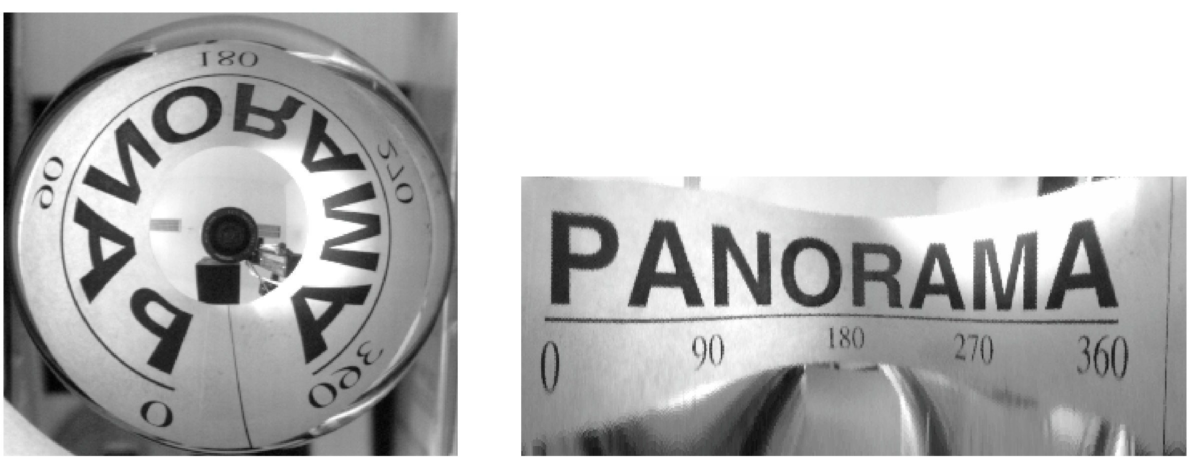


Figure 1. Omni-directional image captured by camera viewing convex mirror (left); same image reprojected onto cylindrical surface (right).

Applying omni-directional vision to the field of mobile robotics could yield more efficient and dexterous robots. A robot with standard single-direction vision may lose a target it is tracking if the target moves out of the robot's field of view. The robot would then be forced to stop and scan for the target before resuming the tracking operation. Omni-directional vision eliminates this problem by expanding the robot's field of view to 360 degrees.

Design Objectives

- Gain knowledge of omni-directional and computer imaging and mobile robotics
- Design and construct the omni-directional imaging apparatus for our mobile robot
- Implement software to control the movement of the robot based on omni-directional images acquired
- Gain experience in the engineering design process including planning, ordering materials, hardware and software implementation, testing and validation, and delivery
- Practice good project management and planning techniques to ensure delivery of our project by the end of the semester

Method of Solution

Survey of Literature, Market, and Existing Components

The project advisors provided us with a website that has links to many projects dealing with omni-directional vision. It was from this site, The Page of Omnidirectional Vision, that we obtained most of our information.

The current market for omni-directional vision applications includes not only mobile robotics, but also video surveillance, security, and virtual reality systems.

We know that the Boe-Bot and the CMUcam are compatible because Parallax sells them together, and we have seen several video clips of these systems in action. Because the sonar and radio frequency transceivers are all sold as accessories to the Boe-Bot, we know that they work individually. Other Boe-Bot experiments with cameras, but not omni-directional

Design Constraints

There several limiting constraints that will affect the design and implementation of the omni-directional vision system for our mobile robot.

- Time – Our project must be completed by the end of the semester.
- Budget – The amount of money we can spend on our project is limited by the professor's discretion.
- Component Availability & Shipping Delays – We must use the components that we will be able to obtain in a timely manner.
- Knowledge – Considering the short time we have studies omni-directional vision and mobile robotics, our design reflects our basic understanding of these subjects.
- Object Avoidance – The robot must avoid collisions with walls, people, and other obstacles.

Feasibility Study

We are confident that our components will work together because the hardware has previously been tested on projects including the CMUcam and the Boe-Bot. The Boe-Bot, coupled with the BASIC stamp, is a fairly inexpensive combination of a robot and microcontroller. The CMUcam user manual offers free software for tracking brightly colored objects which will allow us to have a solid foundation for our new omni-directional software.

Proposed Design Implementation

The omni-visional robot will contain several main hardware components. The following components are the most feasible components found for constructing an omni-directional motion-tracking robot. The Board of Education Robot (Boe-Bot) is the robot chosen for the project. This parallax made robot will offer a solid platform for fastening the camera while also providing a moderately simple interface between the BASIC stamp, robot, and the camera. The BASIC stamp, also developed by parallax, will function as the micro controller. The camera is a CMU-camera developed by Seattle Robotics. In order to create the omni-directional image, a hyperbolic mirror manufactured by Neovision will be fastened to the lens of the camera. A combination of whiskers and sonar devices will be used to prevent the robot from colliding with other objects.

Basic Stamp

The BASIC stamp (Figure 2) will serve as the micro controller for the project. The stamp will provide I/O pins, which can be fully programmed to interface with other components such as LED's, speakers, and other devices. The stamp will include a 5-volt regulator, resonator, serial EEPROM, and PBASIC interpreter.

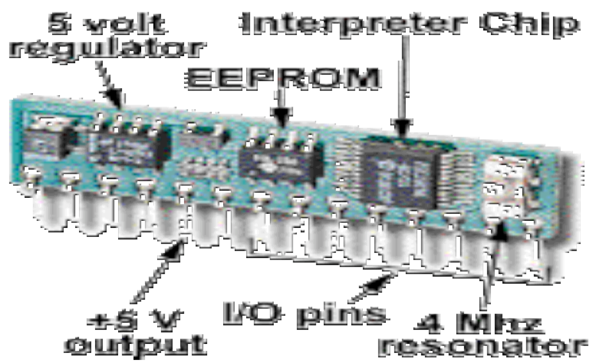


Figure 2. The BASIC stamp.

The EEPROM is a non-volatile memory, which will store the BASIC program received. The BASIC program will be written using the editor supplied by the parallax vendor and can be transferred directly from the PC to the EEPROM through the serial connection. Since it is non-volatile, it will store the program even when power is shut off. The user can erase or write over the program by reloading a new program into the EEPROM. The PBASIC interpreter will fetch and write the instructions to the EEPROM.

The BASIC stamp preferred is the BS2p40, which is manufactured by parallax. The BS2P40 provides several advantages over the other Parallax BASIC stamps. This particular stamp offers 16 extra I/O pins. The stamp offers several new commands for interfacing with a larger variety of components along with a polled interrupt capability feature. The starter kit for the stamp also offers a serial cable, BASIC stamp manual, thermometer, 4K EEPROM, and a 4.7K resistor, which can all be useful for the project. The recommended power supply for the stamp is a 7.5 V DC 1 amp source. The programming language used by the BASIC stamp is the BASIC programming language. The software loaded into the stamp will be used to control the Boe-Bot. The stamp will be plugged into the Boe-Bot. The BASIC program software will set up the serial interface connection between the robot and the CMUcam's own SX28 micro controller. The software will instruct the camera to lock onto and track a brightly colored object. The stamp will command the Boe-Bot to follow the object being tracked based on imaging data sent from the CMUcam and stop when it comes within a specified distance.

CMU Camera

The CMUcam is a fairly common camera used as for robot vision. The Seattle Robotics Company manufactures the CMUcam. The CMUcam camera was chosen because it does not require much power and also can be purchased relatively cheap. A SX28 micro controller is used for handling all the processing of the camera data. It is connected directly to an OV6620 Omni vision C-MOS camera chip. Firmware to handle these tasks must be installed to the micro controller using either a RS-232 or TTL serial port. The serial communication parameters are specified in Table 1.

Table 1. SX28 Microcontroller Serial Communication Parameters

115,200 Baud
8 Data bits
1 stop bit
No parity, and No flow Control.

The camera can be used to output information such as the position of a brightly colored object. The information will be sent to the stamp, which will use the image coordinates to control the robot and advance to the object. The stamp will send instruction commands to the SX28. Each command will be sent using visible ASCII characters. When the transmission is successful, an ACK string will be returned. If the transmission is unsuccessful, a NCK string will be returned. The commands, located in Table 2, are a sample of common examples used to communicate with the CMUcam. They will be integrated into the BASIC program downloaded onto the stamp. All commands will be followed by either an ACK or a NCK reply from the CMUcam notifying whether or not the transmission was successful.

Table 2. Sample CMUcam Commands

Command	Description
\r	Sets the camera into an idle state. The camera should return an ACK acknowledgement
CR [reg1 value1]\r	This command will set the internal registers of the camera. The user can send up to 16 register-value combinations. To reset the camera and restore the camera registers to their default state, simply call this command with no arguments.
DF\r	This command will dump a frame out to the micro controller via the serial port. This dumped data will consist of raw video data column by column and also consisting of a frame synchronize byte and column synchronize byte.
L1 value\r	This command is used to control the green LED tracking light. The three possible values are 0, 1, and 2. 2 is the default auto mode. 0 disables the tracking light and 1 turns the tracking light on.
DM value\r	This command sets the delay before packets that are transmitted over the serial port. The possible delay values range from 0-255.

The CMUcam operates at 17 frames per second, which will be sufficient for the project. The main purpose of the CMUcam will be to lock on a brightly colored object and track it. The camera will supply the robot with an image and the robot will use the image to gather coordinates and move to the target. The camera will be pointed vertically straight up with the hyperbolic mirrors fastened to the lens. This will enable the robot to see a full 360-degree picture. When tracking a brightly colored object using the CMUcam, it is important to follow the following calibration procedure:

1. Make sure the camera currently has no objects in front of it.
2. Hold and release the Boe-Bot reset button.
3. After a 1 second delay, the green LED on the CMUcam will turn on for about 5 seconds as the camera adjusts to the lighting.
4. Once the green light turns off, the user will have 5 seconds to place the object in front of the robot and allow the robot to lock onto the object.
5. The green light will illuminate again once the robot has locked onto the object.
6. The camera will now track the objects of that particular color.

Boe-Bot (Board of Education robot)

The Boe-Bot will require assembly upon arrival from the vendor. The Boe-Bot is built on an aluminum chassis which will include a breadboard, battery pack, two servos, wheels, along with other smaller components. The breadboard will offer a platform for connecting other devices and adding circuitry. The Boe-Bot can be programmed to perform many functions. Once the assembly has been made, testing must be done to ensure all components work properly. The Boe-Bot includes two servos or wheel motors which will be used to control the path of the robot. An electric engine also known as a pulse train will control the servos. The pre-modified servos will be pulsed in such a way as to control the wheel to turn a full 360 degrees continuously in either a clockwise or counterclockwise direction. The pulse widths will range between 1 ms and 2 ms. At 1.5 ms pulses, the servo will stay still. At 2 ms pulses, the servo will rotate at full speed in the counter clockwise direction. Likewise, when the pulses are less than 1.5 ms, the servo will rotate at a clockwise direction with 1 ms being the fastest speed. The software in the BASIC stamp will control how much each wheel should turn in order to advance the robot towards the object that the camera is tracking.

Hyperbolic mirror

A hyperbolic mirror will be needed to accomplish the 360-degree omni visional image. The mirror chosen will be a half spherical shaped mirror developed by Neovision. The mirror will be fastened to the lens of the vertically mounted upward CMUcam camera. The lens of the camera will be located at the focal point of the mirror to ensure that the image will be correct. The mirror will be made of glass.

Collision prevention

Wires (whiskers) and a sonar device will be fastened to the sides of the robot to help prevent it from running into walls or other obstacles. The whiskers will allow the robot to avoid obstacles by touch. The robot will then change direction and continue without colliding into the object. The whiskers will be wired to the Boe-Bot through the supplied Boe-Bot breadboard. Each switch circuit I/O pins will use the 10 KΩ pull-up resistors to monitor their individual voltages. When the whiskers are free, the voltage at the I/O pin should be around 5 volts. When the whisker is touched, the line is shorted to ground returning a voltage value of 0 V. The I/O line will see logic 0 rather than logic 1. The BASIC stamp will be programmed to detect when a whisker has physical contact with another object. A sonar device will also be used. The sonar device will send out sonar waves, which will bounce back to the receiver. If an obstacle is in the sonar path and too close, the receiver will receive the waves quicker than expected and adjust its path to avoid the obstacle.

Alternative Solutions

There are several alternative solutions to the design problem. One solution would be to use different types of mirrors. There are three main types of mirrors: conical, parabolic and spherical (Figure 3). Parabolic is our choice due to the limited distortion of the images. Spherical tends to warp the image increasingly more, the further away from the camera the image gets. Conical mirrors tend to reflect the image more downward than straight out from the camera.

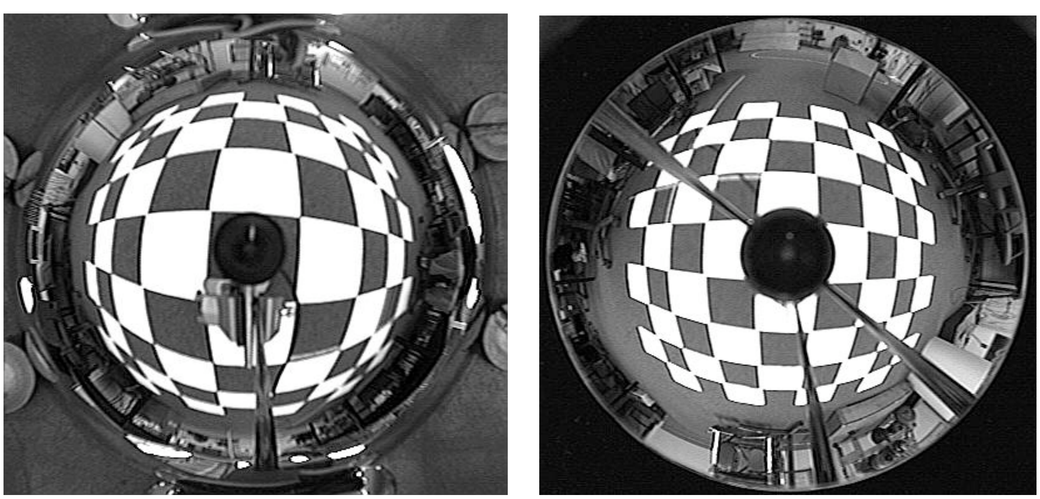


Figure 3. Spherical mirror (left) and parabolic mirror(right).

Another alternative solution is to use multiple cameras. Cameras can point in different directions providing a view of the varying directions. There are several problems with this solution. One such downfall is the lack of one continuous image. The arrangement produces several different images instead of one single image. One could stitch the image back together using software, but this adds a great deal of complexity to the design. Simply having multiple cameras increases the complexity and also increase the hardware needs of the micro controller. The greatest downfall of this solution is the escalation in cost. Even inexpensive cameras will cost over $100. This would quickly put us well over budget.

A third solution is also available. Instead of using mirrors, we would use a super-wide angle "fish eye" lens. The lens distorts the light entering the lens and provides a large field of view. This is also an economical solution. The down fall of this alternative, is the relative limited field of view provided compared to that of the parabolic mirror.

Design Validation Approach

We must fully test the end product in order to insure that the robot and vision system design match all the appropriate design criteria. For the basic project, we will have to test the entire vision field to validate that the robot senses and tracks the desired object over the full 360-degree field. This can be accomplished by moving the desired target completely around the robot faster than the robot can respond so that it verifies that the target object is never lost.

Moving an object and thus the robot down corridors with trashcans or other objects that may impede its path can test obstacle avoidance. The sonar and whiskers will have to detect and navigate the robot away from said object and the vision system will maintain visual contact with the target at all times. Obstacle avoidance is critical to prevent damage to the robot, camera system, and external environment.

A standardized checklist may be as follows:

Robot successfully tracks the object in front of robot:
Robot successfully tracks the object on left side:
Robot successfully tracks the object on the right side:
Robot successfully tracks the object from behind:
Rapidly move object from front to back to insure visual tracking system:
Tag a human with the tracking object and move around the building:

Additional Considerations and Analyses

Economic Analysis

Part	Part Number	Vendor	Cost	Quantity	Total Cost
Boe-Bot	28132	Parallax	$229.00	1	$229.00
CMUcam System	30051	Parallax	$139.00	1	$139.00
Devantech SRF04 Ultrasonic Ranger	28015	Parallax	$30.00	1	$30.00
Hyperbolic Mirror for Omni-directional Vision	H3G	Neovision	$290.00	1	$290.00
BASIC STAMP upgrade	BS2P24-IC	Parallax	$79.00	1	$79.00
Miscellaneous Parts	varied	Radio Shack / Lowe's	$60.00	1	$60.00
□	□	□	□	□	□

Possible budget additions if expansion projects are taken on
Phase II a

Boe-Bot	28132	Parallax	$229.00	1	$229.00
CMUcam System	30051	Parallax	$139.00	1	$139.00
Devantech SRF04 Ultrasonic Ranger	28015	Parallax	$30.00	1	$30.00
Hyperbolic Mirror for Omni-directional Vision	H3G	Neovision	$290.00	1	$290.00
BASIC STAMP upgrade	BS2P24-IC	Parallax	$79.00	1	$79.00
Phase II b	□	□	□	□	□
433.92 MHz Transceiver (SIP/solid/raw)	27997	Parallax	$95.00	3	$285.00
□	□	□	□	□	□
□	□	Total Cost before expansion =			$827.00
□	□	Total Proposed Cost for Phase IIa =			$1,594.00
□	□	Total Proposed Cost for Phase IIb =			$1,112.00

Boe-Bot by Parallax, Inc.

Parallax, Inc provides a lightweight, general robotics and student version of a pre-fabricated robot known as the Boe-Bot. This robot meets the general design requirements for the specified project because it is relatively cheap, comes with on-board electronics, and programming software. The main modifications that will be made to the robot will be in the form of adding addition hardware and vision components to allow the omni-directional vision system.

Compared to other pre-fabrication robots, the Boe-Bot is the cheapest and most versatile with a multitude of available accessories from Parallax, Inc.

CMUcam System:

The CMUcam system was originally designed by Carnegie Melon University and is specially modified by Parallax to seamlessly integrate with the Boe-Bot platform. The connection method to the robot only requires a couple of screws and plugging in the serial components so that the stamp onboard the robot can interpret the data sent to it. The CMUcam already contains the hardware necessary for image tracking, pattern locking onto a specific target, and the interface necessary for control the wheel servos for movement. With a few modifications, the CMUcam may be able to lock onto a target of a specified color rather than having to use the pattern lock feature that is already implemented in the hardware.

Devantech SRF04 Ultrasonic Ranger:

In order to complete the task of obstacle avoidance, the Boe-Bot will have to be outfitted with electronic whiskers and sonar devices. The whiskers come as part of the Boe-Bot full kit but the sonar devices have to be purchased separate. Once again, Parallax, Inc. already has sonar devices on a printed circuit board and ready for integration into the Boe-Bot platform. These sonar devices have a range of 3cm to 3m, which should allow for plenty of control and collision detection.

Hyperbolic Mirror for Omni-directional Vision:

In order to achieve the 360-degree field of vision required for the project, we must use some sort of conical or hyperbolic mirror to reflect a complete image into the camera lens. Through this reflection, the camera and thus the robot will have a 360-degree field of view in a single frame shot without the need for camera rotation. Currently, the cheapest vendor for said mirror is

Neovision in the Czech Republic. They can build a 25mm diameter hyperbolic lens, which would reflect the appropriate image for $290. Compared to other vendors, Neovision presents the cheapest option as Accowle, Inc. in Japan sells similar mirrors for $430 to $800.

BASIC STAMP upgrade:

Viewing the project description and to allow for the most flexibility and expandability for design, we have opted to upgrade our stamp package to the BS2P24-IC. This particular stamp has 19 more BASIC commands, processes approximately 3 times the instructions per second, has more on-board memory, faster serial port communication speeds, and faster processor speed, which may be necessary if we take on the expansion phase projects. Essentially, the BS2P24-IC combines the most functionality and most flexibility for the robot for modest price increase.

Miscellaneous Parts:

The miscellaneous parts heading consists of the numerous pieces necessary to make the Boe-Bot functional. This budgetary calculation is based on the cost of batteries, protoboards, wires, solder, mirror mount hardware, and other small pieces necessary to make everything work together. The reason there is no itemized list of parts and costs is because the mirror itself has yet to arrive, and thus it is impossible to determine exactly what is needed to mount it properly. Also, the number of protoboards and wires is completely dependent on how complex the project becomes as more hardware is custom crafted rather than purchased as plug and play components.

433.92 MHz Transceiver (SIP/solid/raw):

Parallax, Inc. offers transceivers ready built and all that is necessary is to connect the serial port and power them. If the computer controlled extension is taken, then transceivers for both the computer and robot(s) would be needed causing the specification for 3 transceivers. These transceivers have a 2-inch antenna and transmission range of 150 feet. It is noted that in a budget crunch, a self-built transceiver could be constructed for approximately $28 each but would require the obtainment of new printed circuit boards or protoboards in order to connect the transmitter, receiver, and antennae. These materials would be purchased from Reynolds Electronics in model numbers TWS-434, RWS-434, and 434 MHz for the transmitter, receiver, and antenna respectively. It must be noted, however, that by custom building this component it would be much more complex and require more testing time to ensure the construction was done properly.

Environmental, Societal and Safety Analysis

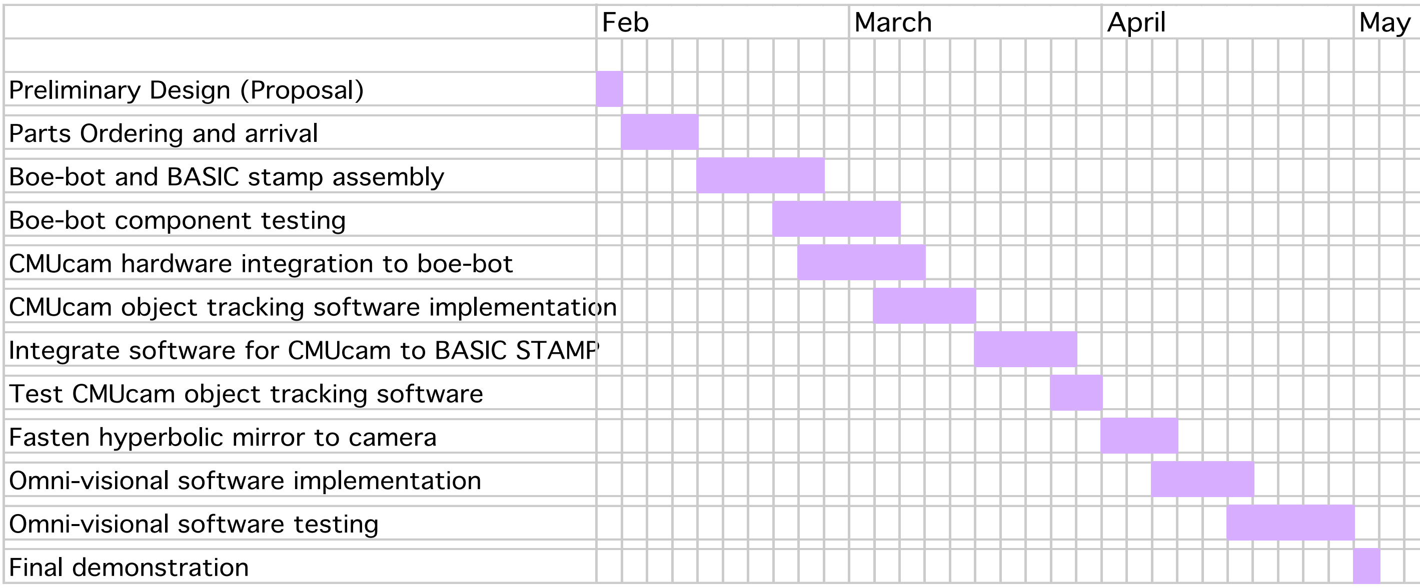
The environmental concerns associated with our robot and omni-directional vision system are minimal. The robot itself is small, 127 millimeters in its largest dimension, weighs about three pounds, and is relatively slow-moving; thus, the danger from impact is negligible.

Power is supplied to the robot in the form of four AAA batteries. Proper disposal of used batteries is required to ensure environmental safety. The robot and imaging devices include no other hazardous materials.

The robot will include two sonar units for collision avoidance. The sonar units emit ultrasonic pulses which will allow the robot to determine its distance from obstacles. While there are no environmental or safety concerns associated with sonar, it does carry the possibility of interfering with other sonar devices and delicate equipment, such as in a research environment.

Proposed Schedule and Work Breakdown

We have developed the following Gantt and PERT charts to assist in planning our design.


Feb
March
April
May
Preliminary Design (Proposal)
Parts Ordering and arrival
Boe-bot and BASIC stamp assembly
Boe-bot component testing
CMUcam hardware integration to boe-bot
CMUcam object tracking software implementation
Integrate software for CMUcam to BASIC STAMP
Test CMUcam object tracking software
Fasten hyperbolic mirror to camera
Omni-visional software implementation
Omni-visional software testing
Final demonstration

Conclusion

The A Team feels that the requirements proposed in this document for the omni-directional vision system for the Parallax Boe-Bot can be completed satisfactorily within the next three months. After careful consideration and deliberation, we have selected all the major components and are ready to begin purchasing. The Gantt and PERT charts will be valuable tools in assisting with project scheduling and ensuring we meet our final deadline.

Considering the rarity of omni-visional robot projects, we felt that our project was both challenging and innovative. The project touched a variety of engineering areas including writing and testing software, integrating hardware, and understanding optics. The base design allows for expandability and future experimentation within the omni-directional vision control system fields. Hopefully with future innovations and research, this particular design can become the backbone for other researchers' fields of study.

References

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