NavBot: The Navigational Search-and-Rescue Robot

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Abstract

This paper describes The Stony Brook Robot Design Team's entry into the Scavenger Hunt Event at the 2005 American Association of Artificial Intelligence [AAAI] Robot Competition and Exhibition. The team has focused on two main areas of research in the creation of NavBot: structural design and computer vision. Our goal was to build an intelligent machine from scratch that could navigate the conference floor and detect specific objects at the AAAI Conference in Pittsburgh, Pennsylvania.

Introduction

In its first year, the Scavenger Hunt Competition was the focus of our efforts. Robots participating in the Scavenger Hunt event at AAAI must locate objects of varying shapes and color in an active area of the conference hotel floor. Objects included small toys, articles of clothing, and storage bins. This challenge required teams to push their navigational algorithms and vision capabilities to their absolute limits to remain competitive.

Teams were encouraged to participate in two separate events to demonstrate the abilities of their robot(s). In the Scavenger Hunt Exhibition, teams had the freedom to customize their demonstration of the capabilities of their robotic systems in a controlled setting. With this relatively unstructured environment, a collection of robots from different fields, such as Urban Search-and-Rescue [USR] or social interaction, were able to participate (Blank 2005). NavBot participated in this competition because it will also compete in future events as a search-and-rescue robot.

The Scavenger Hunt Predetermined Challenge was an elaborately designed competition where all participants followed the same competition guidelines. Teams had their robotic systems locate a fixed list of objects in an active conference area. Robots were able to demonstrate any of their Artificial Intelligence capabilities, which were not limited to computer vision and auditory recognition functionalities. Objects in the scavenger hunt included those with visual and auditory cues. In addition to a given list of items, competition organizers added items of their choice on the day of the competition (Blank 2005). We believe the vital functionalities of a successful robot include robust color detection, shape detection, and mapping capabilities.

A panel of judges selected from the conference evaluated the performance of robotics systems. Robots needed to indicate that objects were found through a clearly interpreted form of communication, such as speech. In addition to overall success, navigational algorithms, environment mapping, object detection, object handling, multiple robot coordination, and innovative design were strongly considered in calculating a team's score (Blank 2005). For example, NavBot's custom-designed mechanical lift and camera mount would be incorporated into its evaluation.

For the first year of the three-year NavBot project, the Stony Brook Robot Design Team constructed the robot's mechanical exterior, began circuit board design, and developed a prototype of its navigation algorithm. The team has also begun integrating vision into its software.

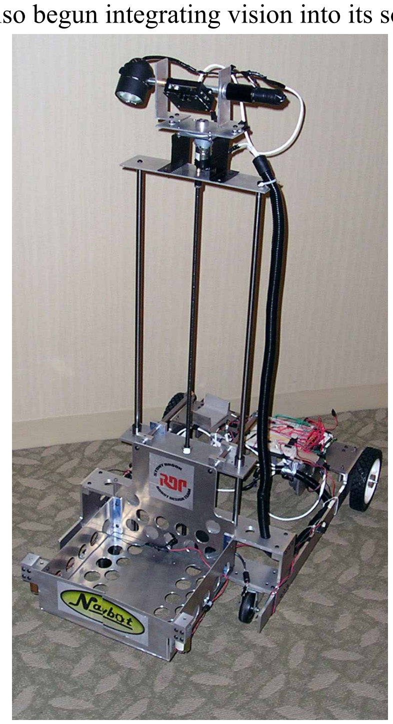

Figure 1: Current view of the NavBot project.

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Mechanical Structure

To achieve the desirable speeds needed in a rescue robot, NavBot utilizes two high-rpm servo motors with a manually adjustable gear train. The 12V servo motors enhance the maneuverability of the robot by providing minor adjustments in the robot's speed as it navigates the room. The manually adjustable gear trains allow NavBot to function in different environments. This flexibility is achieved by controlling the force and the speed required for movement in the terrain. To improve the sturdiness of NavBot, a light aluminum skeleton was designed. In addition to the large space provided for necessary electrical and computer equipment, the skeleton serves as a secure casing to prevent damage to vital parts.

Since the objects in the AAAI Scavenger Hunt Event can be located at various heights, NavBot is equipped with a linear vertical motion system. The motion system enables the robot's arm-like appendage to reach objects between 0 feet and 2.5 feet. This arm is implemented using two shafts placed close together to form a column. An acme rod is used to transform the rotational motion of a servo motor into the vertical motion of an attached box-like cart. The cart is designed with a front opening to grip and enclose objects that are captured. The two front opening doors are controlled by high-torque gear motors. This universal gripping mechanism captures objects of various shapes and sizes.

Figure 2: Linear vertical motion system of NavBot.

A camera mount is positioned above the gripping mechanism in order to provide NavBot with an excellent line of sight toward objects. Housed within a Fused Disposition Modeling-prototyped box and shielded by a polycarbonate plate, a CMUCam2 camera is flanked by a horizontal servo motor and a shielded halogen lamp. The motor enables horizontal rotation of the protected camera. The lamp provides a stable source of light that optimizes color recognition by the camera. A second servo motor underneath this setup allows for rotation along the vertical axis. Through the use of two servo motors, this camera can pivot with two degrees of freedom. Together, the motors rotate the camera with approximately 140 degrees of freedom in the horizontal axis and 360 degrees of freedom in the vertical axis.

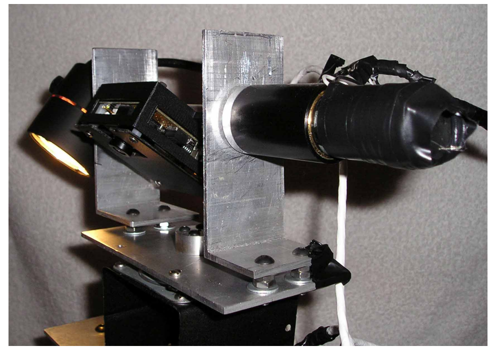


Figure 3: NavBot camera mount.

Electrical Design

NavBot's vision system requires both sensors and wired communication between parts to operate effectively. Multiple infrared sensors enable NavBot to detect objects in its path.

Savage Innovation's OOPic-R Microprocessor acts as NavBot's brain, controlling all hardware operations. Its compiler allows the implementation of Java, Basic, and C to develop its navigation software, which is necessary to create a strong autonomous system. An exceptional feature of the OOPic-R is its virtual circuits, which allow multitasking, where objects within NavBot pass information to each other. Navbot has infrared sensors connected to the OOPic-R, which permit better navigation. The OOPic-R retrieves color and position information from a CMUcam2 camera, allowing NavBot to adapt to its environment.

Infrared Interface

For all moving robots, obstacle detection is one of the primary tasks that needs to be realized to prevent hazardous conditions. We chose infrared sensors against all other moderately affordable methods because of their reliability, range of operation, and ease of use.

The infrared device used in this design was the Sharp GP2D12 Infrared Sensor. It is a commonly used device with three pins consisting of supply, ground, and analog voltage output, respectively. It functions by taking constant readings and converting these readings to the form of an output voltage which varies according to the distance between itself and an object (Savage Innovations 2004).

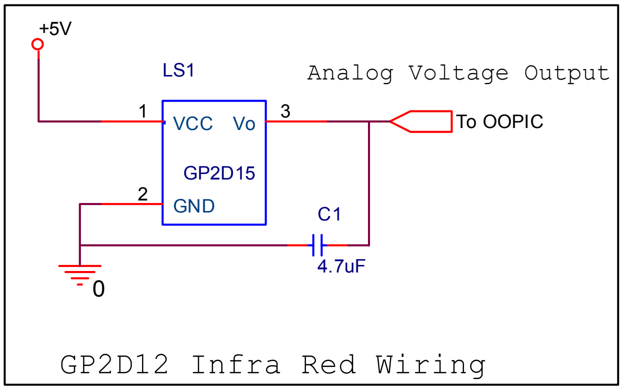


Figure 4: Interface to the OOPic microcontroller.

The microcontroller has a specific pinout for interfacing with the sensor device, which is known as the Analog to Digital I/O line. The microcontroller converts the analog voltage output received from this line to an 8-bit value (Savage Innovations 2004).

The voltage can range from 0.01V to 2.45V, while the distance ranges between 10 centimeters and 80 centimeters. However, the relationship between output voltage and distance is non-linear. The measurements are taken in 0.01V increments. Since these readings are not ideal and have some noise components, the voltage measurements may not be as smooth as intended (Savage Innovations 2004). Therefore, a capacitor connected as shown above smoothes out the voltage outputs for more accurate readings.

Programmers can manipulate the robot's movements using information contained in the 8-bit value obtained from the output voltage conversion. This provides relatively straightforward interfacing between hardware and software.

Motor Control

NavBot's motors are controlled by four quadruple half H-Bridge motor drivers. The chip implemented in this design was the SN754410, a quite stable design for such implementations, but very vulnerable to slight errors in wiring.

The chip was wired as shown in Figure 5, adhering to the manufacturer's recommendations as a cautionary measure (Texas Instruments, Inc. 1995). Each chip has the potential of controlling two motors, and therefore four such chips were used for complete control on all the motors present in the design. The labeled pins are then wired onto the microcontroller's I/O pins for programming the interface.

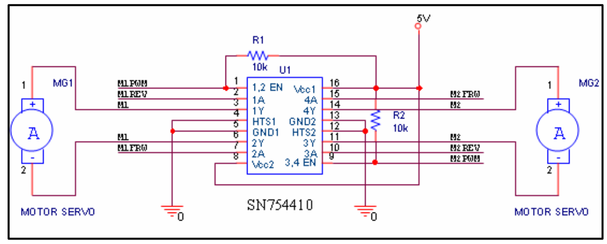
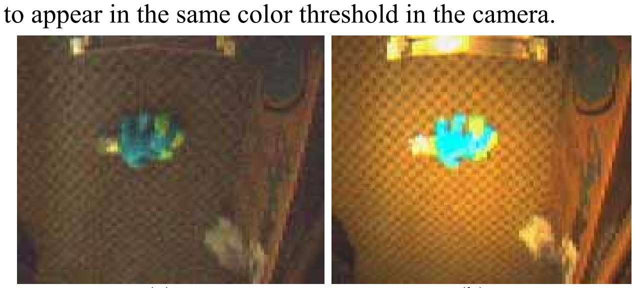


Figure 5: Basic H-Bridge circuit wiring.

Vision and Navigation Systems

NavBot relies on a CMUcam2 Vision Sensor to capture images of its surroundings. The CMUcam2 is designed using an Ubicom SX52 processor that processes at 75 MHz. We chose this module specifically for its ability to easily handle vision algorithms. Its color tracking functionalities allow it to differentiate objects without difficulty. The resolution of the CMUcam2 can be up to 160 x 256 pixels, which can capture objects up to 3 meters away (Rowe 2003). Therefore, this requires the robot to navigate an environment while the camera searches for objects in a rotation with 360 degrees of freedom. Since the CMUcam2 can only capture pictures during motion of up to 26 frames per second, we opted to have NavBot operate at low speeds. In future research, the camera will also be used to capture whole images when it finds objects and will incorporate edge detection algorithms to localize the object dimensions identified by the computer.

Since the competition takes place in an insufficient light environment, an image correction technique is used to reduce the visual noise and improve the color uniformity of objects viewed by the CMUcam2. This technique is achieved by using a high-luminosity halogen flashlight that can operate on 12 volts, but consumes less power than typical light bulbs. This light also has excellent uniformity and concentration, which allows similar colors of an object to appear in the same color threshold in the camera.



(a) (b)

Figure 6: Comparison of CMUcam2 color detection (a) without illumination, and (b) with illumination.

NavBot is also equipped with a 1.80 GHz Intel Centrino laptop. The laptop is light and is powered by its own batteries, which reduces the need for another power source. However, its most important function is to communicate with the camera and the microcontroller through an RS232 serial connection. This is achieved with a high baud rate of 115,200 bits per second. The computer will also be used to draw the navigational map used for robot localization.

The navigational control algorithm is currently under development. A prototype was demonstrated at the competition, where NavBot detected an object within a specified color threshold, approached it, and placed it within its cart. We developed this software in the OOPic-R Integrated Development Environment under its Basic interpreter.

Results and Evaluation

The Scavenger Hunt Exhibition allowed us to realize strengths and weaknesses of our current version of the NavBot project. We found that our mechanical design proved to be efficient for its vision and navigational capabilities. However, while testing at the competition, we encountered challenges with the electrical implementation of our robot.

Our decision to mount the camera on the upper portion of the robot, alongside the halogen light, permitted the robot to view an appropriate span of the competition floor. The cart's ability to capture objects clearly demonstrated to judges when NavBot successfully located a desired object. Furthermore, the slim design of NavBot's hull prevents it from disturbing other objects that may be in the competition area, such as furniture.

For the NavBot project's first year of development, we chose to build our circuit boards from scratch, soldering wires onto the interface as necessary. However, the extreme sensitivity of our electrical design meant that the slightest mistake could damage an entire board. Unfortunately during testing at the competition, one of our boards failed. To approach the challenging task of rewiring, we implemented the circuit design on a breadboard. This allowed us to test our robot's navigational and mechanical controls with a considerably more durable structure. We intend to design and print custom circuit boards for use in future competitions.

The robust color tracking system we demonstrated at the competition has laid the foundation for future development of NavBot's software. NavBot tracks solid-colored objects by establishing color thresholds of captured reference images. Coupled with illumination of its viewing area, we believe multiple-color detection, motion detection, and object detection are highly approachable vision tasks for the NavBot project.

Conclusions and Future Work

Our design choices were motivated by low cost, the versatility to customize our platform for multiple projects, and a drive for interdisciplinary research. With the cost of approximately $2,500, the NavBot project has remained fairly cost-effective. A majority of NavBot's parts were designed and built by undergraduate students from the Stony Brook Robot Design Team, with the guidance and support of the team's research advisors. This customizable robotic structure will allow us to pursue upcoming USR and Scavenger Hunt Competitions.

Since members of the robotics team belong to the Mechanical Engineering, Electrical Engineering, and Computer Science Departments of Stony Brook University, the NavBot project has been a strong interdisciplinary effort. Furthermore, future research will require innovations from all three disciplines. The team's ability to work collaboratively was noted at the competition, as the Stony Brook Robot Design Team received Honorable Mention for Interdisciplinary Field Integration.

Future research will focus on developing NavBot's Vision and Navigation Systems. We will be expanding our AI component into motion tracking and object detection. In addition, we will be integrating sonar sensors into the robot's obstacle detection system. These research efforts will improve the efficacy of NavBot's vision capabilities.

To localize NavBot, more onboard cameras will be added for constructing a map of its environment. Possible localization algorithms include implementation of DP-SLAM from Duke University (Eliazar and Parr 2004). Our additional sensors will help to avoid placing markers. The objective will be to have a fully autonomous robot operating efficiently in an unstructured environment.

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