EGOR: Design, Development, Implementation
An Entry in the 1994 AAAI Robot Competition

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Abstract

EGOR, an entry in the 1994 AAAI Robot Competition, was built by a team from the Department of Computer Science at the University of Utah. The constraints imposed by the competition rules, and by cost and time, led to the development of a system composed of *off-the-shelf* parts based on a mobile base built by Transitions Research Corporation and an Intel 486DX33-based laptop computer. The work included design, subsystem part procurement, fabrication, software development, testing, and system evaluation.

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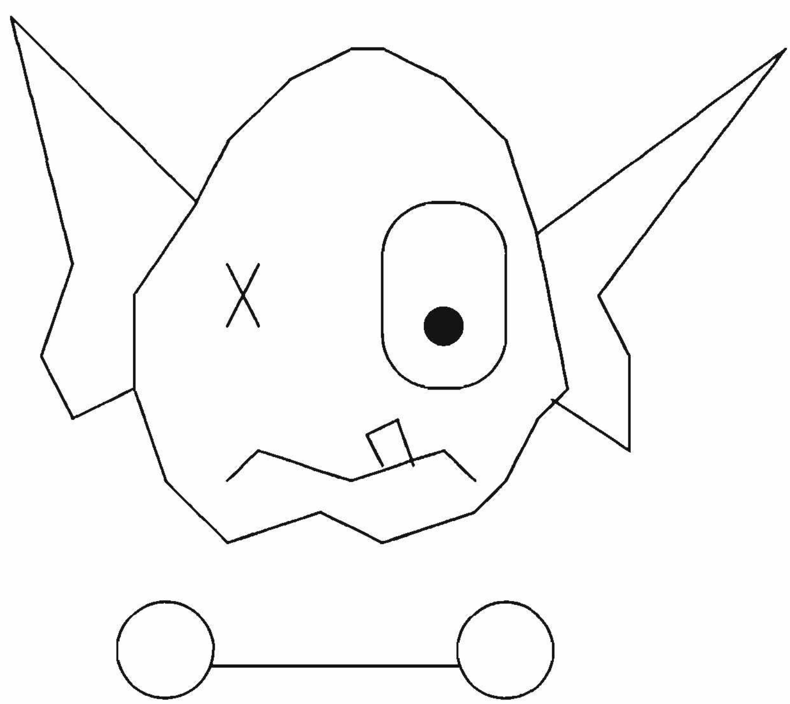

What Hump?

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Chapter 1

Introduction

In January 1994, the authors decided to build an entry for the AAAI Robot Competition to be held in Seattle at the end of July 1994. This report details the design, development, and implementation of that robot. Because of the short lead time before the contest, we decided to use the Transitions Research Corporation (TRC) Labmate mobile robot base and Proximity Subsystem, because this system was already at the University of Utah as the result of another research program (see Figure 1.1). For the sake of simplicity and expediency, we decided to use off-the-shelf components for the rest of the system as much as possible.

Since large, off-the-shelf "body" parts were to be used to assemble our autonomous agent, he was named EGOR (Everybody's Good Old Robot), a play on words referring to the Gene Wilder - Marty Feldman pair who assembled another autonomous agent in the comedy classic *Young Frankenstein.* In addition, when he was given speech, he was provided with an authentic Slavic accent, courtesy of Alyosha Efros. Hence, his three favorite expressions are:

- What hump?
- Yes, Master.
- Walk this way.

In a more serious vein, the wide availability of add-on boards and software for PC clones made it seem likely that this off-the-shelf approach to building our robot entry would not require much engineering, except at the "cut and paste" level. It would also make problem diagnosis and repair much simpler. As an added benefit, both hardware and software for these machines are quite "user friendly," since they have to meet the needs of the commercial market. This judgment proved to be reasonable and made the completion of our entry in time for the contest feasible. Figures 1.2, 1.3, and 1.4 show EGOR in his final configuration with camera, speakers, and full complement of sensors.

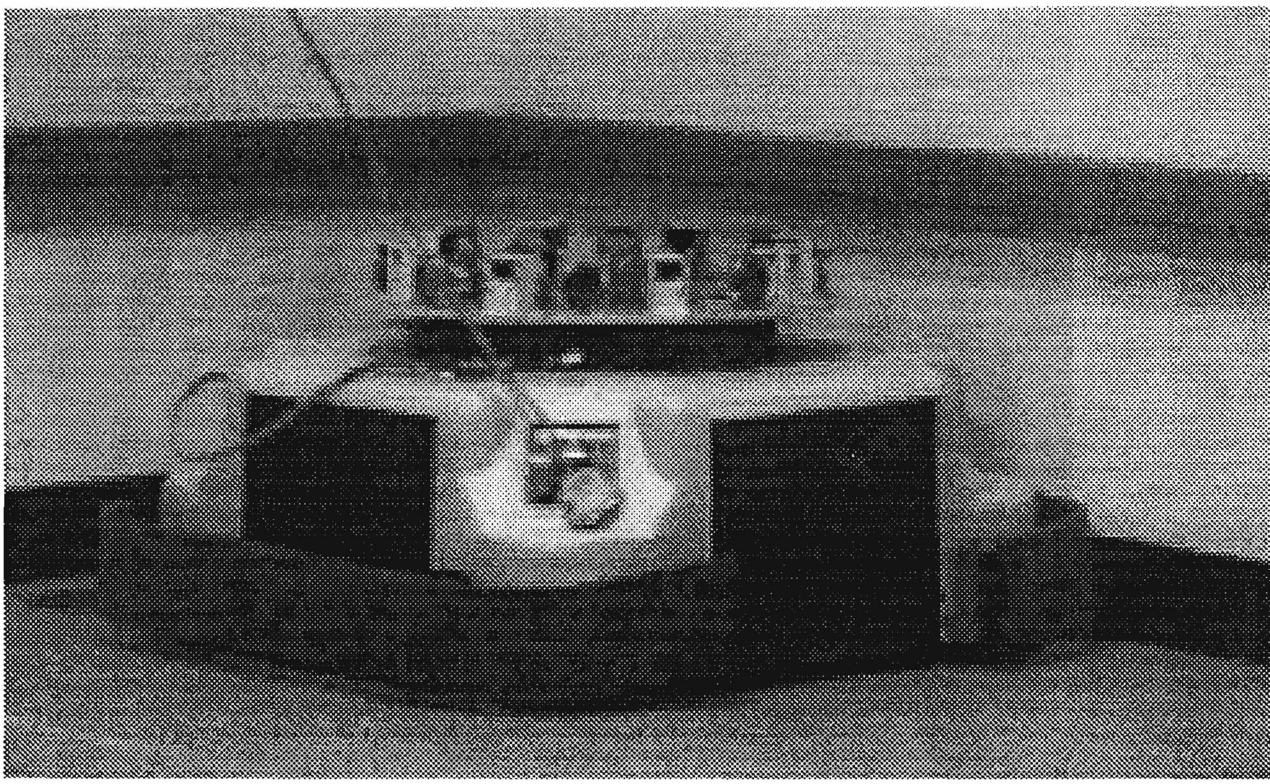

Figure 1.1: Initial Sensor Configuration on Labmate

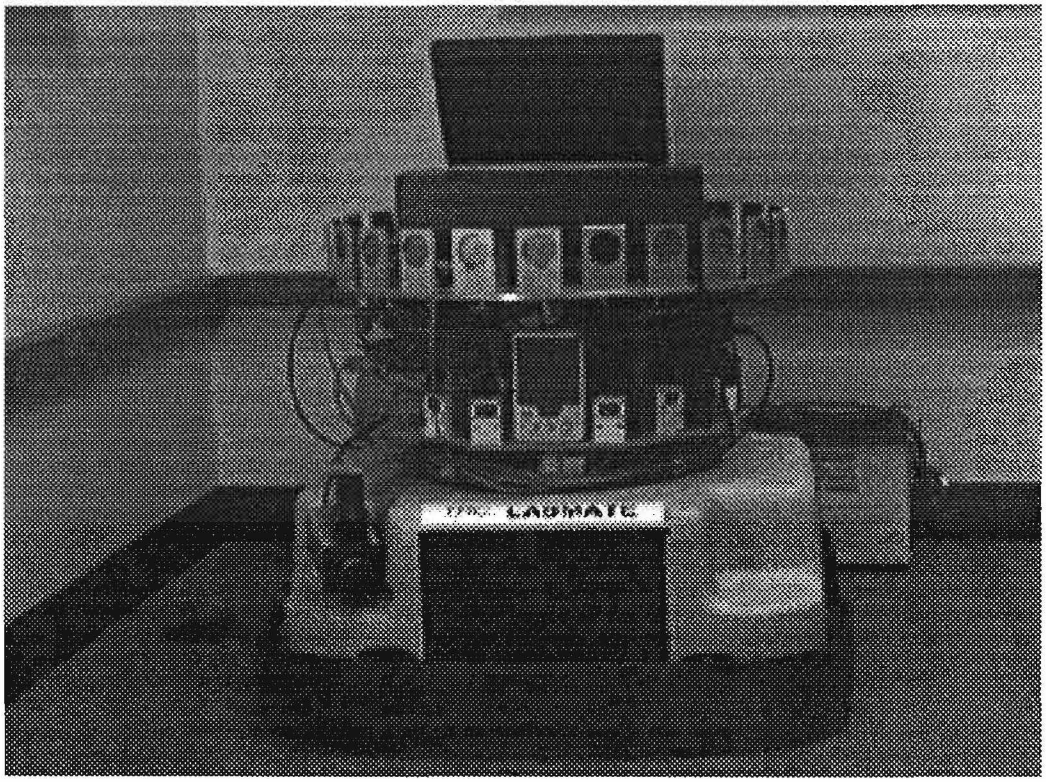

Figure 1.2: EGOR - Final Configuration - Front View

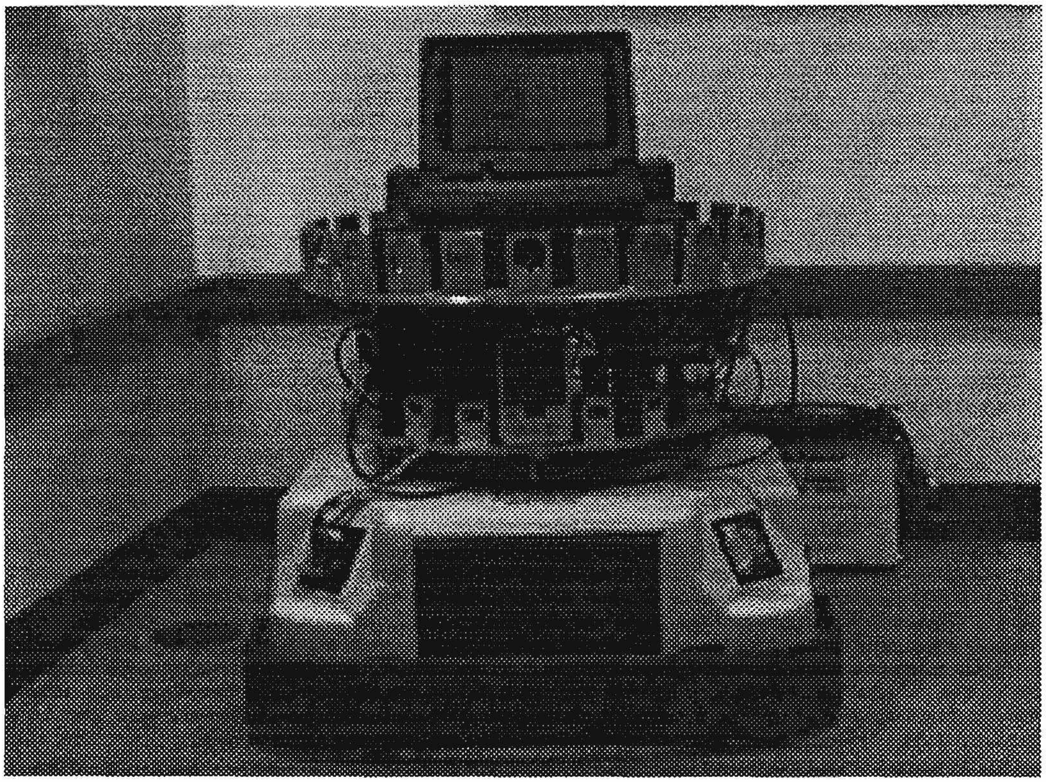

Figure 1.3: EGOR - Final Configuration - Back View

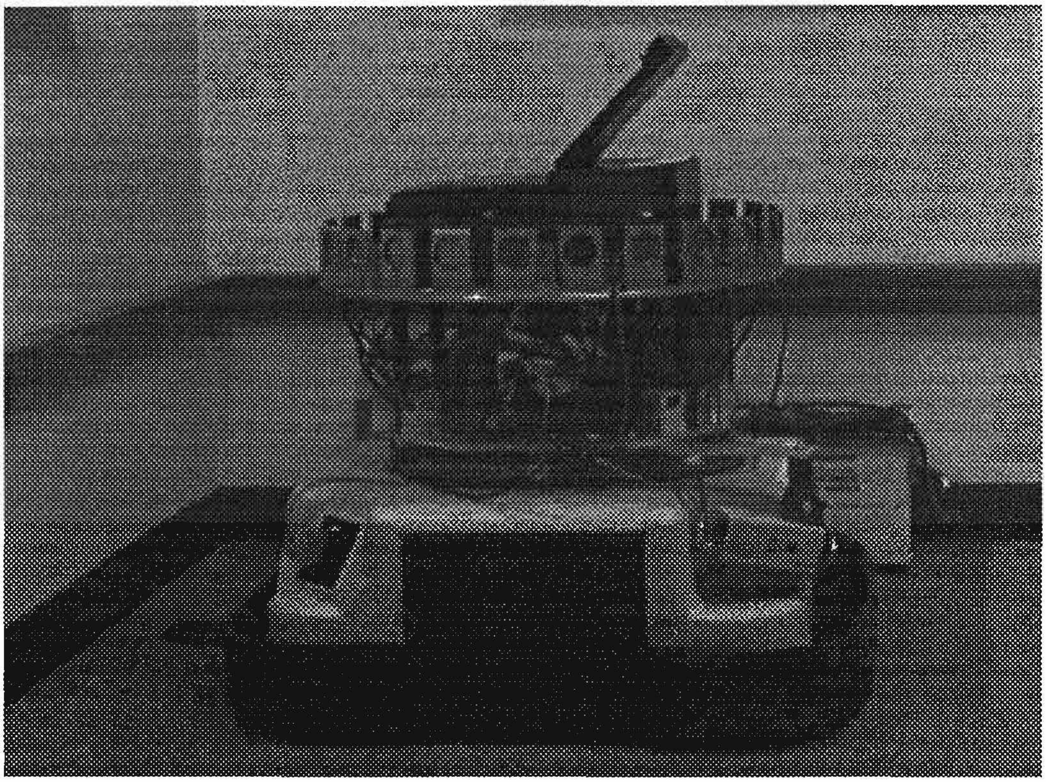

Figure 1.4: EGOR - Final Configuration - Side View

Chapter 2

Design

2.1 Requirements - Event 1

Event 1 of the robot competition required navigating through a simulated office environment. Contestants would be given a topological map of the area before the competition consisting of nodes for rooms, room-hallway intersections, hallway intersections, and connections between nodes with general directions. For each of the three runs, the contestant would be given the starting node and the goal node. The robot's initial direction could also be given but at the cost of penalty points. The second and third runs could have doorways closed, obstacles and hallways blocked requiring the robot, upon detecting a blockage, to select an alternate route to the goal node.

2.1.1 Mobile Platform

The Labmate mobile robot base procured from Transitions Research Corporation in Danbury, Connecticut provided the basic platform. It is capable of carrying loads up to 400 pounds and of speeds of one meter per second. It can be controlled with a joystick or with commands from a host computer over a serial link. Two drive wheels and four corner caster allow movement forward, backward, turns of given radius or rotation in place. Batteries provide power for 2 - 6 hours of operation between recharging using an external charger. Labmate's internal processor not only accepts and executes drive commands from the host computer, but provides wheel positions, velocities, heading, X-Y coordinates and status of several conditions upon request.

2.1.2 UltraSonic and IR Sensor Systems

The Proximity Subsystem, also procured from TRC, consisting of ultrasonic transducers giving range information and IR (infra-red) detectors indicating presence/absence of an object, provided means for the robot to sense its environment. The initial procurement consisted of 8 IR detectors, 8 ultrasonic transducers, 1 interface board, 1 controller board, and some mounting hardware. We later purchased more transducers from Polaroid and two more interface boards from TRC and, with mounting hardware produced in the AML, we arrived at a final configuration of 24 ultrasonic transducers and 8 IR's for our sensor system. Mounting the four printed circuit boards to the underside of the top aluminum plate allowed removal of that plate without disconnecting the transducer cables.

2.1.3 Computer System

The computer system for the mobile robot consisted of a DFI Notebook Computer with a 486DX33 processor, 4-megabyte RAM, 200-megabyte hard drive, $3\frac{1}{2}$-inch floppy disk drive, MS-DOS 6 operating system with windows, and a DFI Docking Station. A docking station is normally used to allow a laptop computer user to have the facilities of a desktop such as modem, connection to a printer, ISA slots for additional cards, extra hard disk and CD drives, a platform for charging the laptop's internal battery, yet keeping the portability and size advantages of a laptop. For EGOR, the docking station provided the extra bus slots, the two required serial ports, as well as a very convenient means of inserting and removing the computer from the rest of the system. The laptop provided all the computing power needed for control of the robot, real-time display of events and sensor returns, C programming, compiling, debugging, testing, data collection and analysis. Software developed on our desktop PC's could easily be transferred to the laptop via floppy disk or the Interlink DOS facility.

2.2 Additional Requirements - Event 2

Event 2 of the robot competition required locating and identifying three types of objects: styrofoam coffee cups, aluminum soda cans, crumpled wads of paper; and move them to a designated receptacle. Robots without arms could use virtual manipulation, i.e., when an object was found and identified the robot could request verbally that a human pick up or deposit the object. Thus this event required mainly video image processing and a small amount of robot movement.

2.2.1 Vision system

To provide for computer vision requirements we purchased a Panasonic WV-BP102 B/W TV camera from a local source and a Win/TV Video Capture Board from Hauppauge Computer Works.

2.3 Equipment Selection Rationale

2.3.1 Labmate Mobile Robot Base

We selected the Labmate mobile robot base since it was already in house, purchased under another contract. This selection gave us a convenient starting platform on which the rest of the system could be fairly rapidly built. The on-board control software can communicate with a host computer using ASCII characters on an RS-232 link (COM line). Driver commands can be sent to the Labmate from the host and information like status, heading, X-Y positions can be received. Labmate's two 60-amp-hour sealed lead-acid batteries provided a basic 24 volts and a regulated +5 and +12 volts to power other system components.

2.3.2 Ultrasonic and Infra-red Sensors

Transitions Research Corporation (TRC), manufacturer of the Labmate mobile robot base, also provided a Proximity Subsystem with the original purchase. This consisted of 8 ultrasonic sensors, 8 infra-red detectors and their control circuit boards. These sensors and the two circuit boards were mounted on an aluminum plate which was mounted on the Labmate base. Using a desktop PC and two 50-foot cables for the serial links, one to the Labmate, one to the Proximity Subsystem, this served as our initial configuration and was used to gain some experience in controlling the Labmate and in evaluating the sensors.

The ultrasonic sensors provided quite precise (within 3 mm) distances to normal surfaces. The IR detectors gave only an indication of the proximity of an object but no information additional to that provided by the ultrasonic sensors.

For the final configuration we purchased 16 more ultrasonic sensors and the two additional boards needed for their control. These 24 sensors arranged in a circle with 15-degree spacing could provide full coverage although in practice only a few sensors were active at a time. The 8 IR's were included in the final configuration but their data were never used.

2.3.3 Computer and Docking Station

The reasoning that went into selection of a labtop computer and docking station was approximately as follows. We first had to decide between using an on-board computer or using a two-channel radio modem driven by a desktop computer. The wireless control would have cost over $6000 as compared to about $2600 for the laptop and docking station. We also had to consider information concerning problems with radio control in previous mobile robot contests and the problem of transmitting video data.

The selection of a laptop computer gave us sufficient computing power for processing sensor data and controlling the Labmate. We were quite confident of this after gaining some experience with a PC with the same processor and operating system using the two umbilical serial control cables. Image processing of TV camera data, though adequate for the competition, proved a little slow. See System Evaluation (Section 5.10). The docking station provided expandability of the PC with ISA slots so we could easily add sound and video cards. Two serial ports were also available.

2.3.4 Voice Recognition

After reading the rules for the mobile robot competition we decided that if we could control the robot with voice commands it might be worth some bonus points. Voice recognition cards were available for PC's and we selected a $289 Microsoft model that we thought provided C program callable procedures which could easily be incorporated into our software. See System Evaluation (Section 5.6) for a discussion of the problems we encountered with voice recognition.

2.3.5 Sound

The mobile robot competition rules required a means of indicating completion of a run in event 1 and asking for virtual manipulation in event 2. Sound cards which write and read .voc and/or .wav files are widely available and relatively inexpensive ($100) and most are compatible with C programs. We expected that the voice recognition card would serve this purpose but it proved incompatible with our C programs so a simpler model was purchased and it performed satisfactorily. Speakers with internal amplifiers were used during the contest to increase volume in the much larger arena.

2.3.6 Video Digitizer

Event 2 of the mobile robot competition required identifying objects like waste baskets, soda cans, etc. We purchased a video card with multiple capabilities including digitizing video images at selectable resolutions. This card was initially inserted in the desktop PC and connected to the TV camera for software development and checkout. It was not moved to the docking station until just before event 2 during the competition in order that software modifications could be made for both events simultaneously.

2.3.7 TV Camera

The selection of the TV camera and a local source was based on advice from people in the Computer Science Department with video expertise. The 12-vdc model was chosen since a regulated 12 volts was available from the Labmate mobile robot base.

2.3.8 Power Conversion

Two options presented themselves in supplying power for the docking station. The docking station internal power supply converts 110 vac to various regulated dc voltages for the PC bus plus charging power for the laptop when it is plugged into the docking station. The initial intention was to replace this power supply with dc-to-dc voltage converters powered by the Labmate's 24-volt battery source. With this approach we ran into some unexpected complexities requiring some engineering and unknown costs and delays.

The alternative approach was to supply the docking station with its normal 110 vac using a 24-volt inverter. This was, on first glance, unattractive due to anticipated power losses in the voltage conversions and the possibility of transients from the inverter switching transistors disrupting the computer. Also, 24-volt inverters are not all that common. With luck, we found a supplier and although the smallest model was 700 watts, its operating efficiency peaked at 95 percent under a 100-watt load which was about the requirement of the docking station. The extra power may prove useful in future applications.

2.4 Instrumentation Mounting

2.4.1 Sensors

The rationale for mounting the ultrasonic sensors at equal angular increments around a circle all at the same height was based on providing the most operational flexibility and because we could find no justification for using any other configuration. After gaining some experience using first an 8-sensor and then, much more extensively a 24-sensor configuration, we have found no reason to change. However, in the future if more area is needed for other equipment, with some rearrangement of the wiring the top aluminum plate can be flipped over, thus putting the sensors on the under side of the plate rather than the top side.

The eight IR sensors were first mounted at equal angular increments between the ultrasonic sensors and in the final configuration were grouped four in front and four in the rear since this seemed the most reasonable placement for proximity detectors for safety considerations.

2.4.2 Computer

The docking station and computer had to be mounted on top for easy access to the keyboard and for viewing the computer screen. Without a great deal of discomfort one could sit on a chair, straddle the Labmate from the rear and perform the oft-needed debugging and modifications to the software.

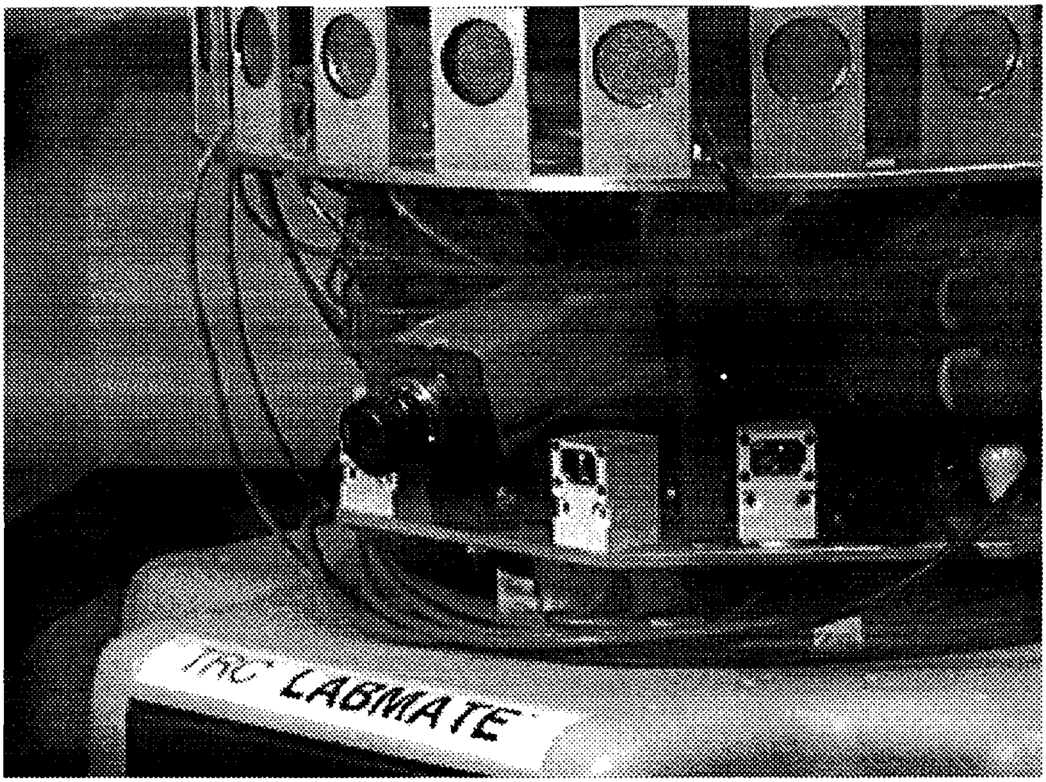

Figure 2.1: Initial Camera Mount Location

2.4.3 Camera

Our initial intention was to mount the TV camera on the front center of the bottom plate, tilted downward as necessary. This position proved to be too high for our field of view when we started looking for objects at various distances. Using a home-made swivel-tilt head, we next tried mounting the the camera directly to the Labmate fiberglass cover above the front-right caster. This proved to be too unstable so an aluminum strip was bolted to the bottom plate and the camera was suspended below this to the desired position, tilted down slightly and to the left to view objects in front of the Labmate. (See Figures 2.1, 2.2, and 2.3.)

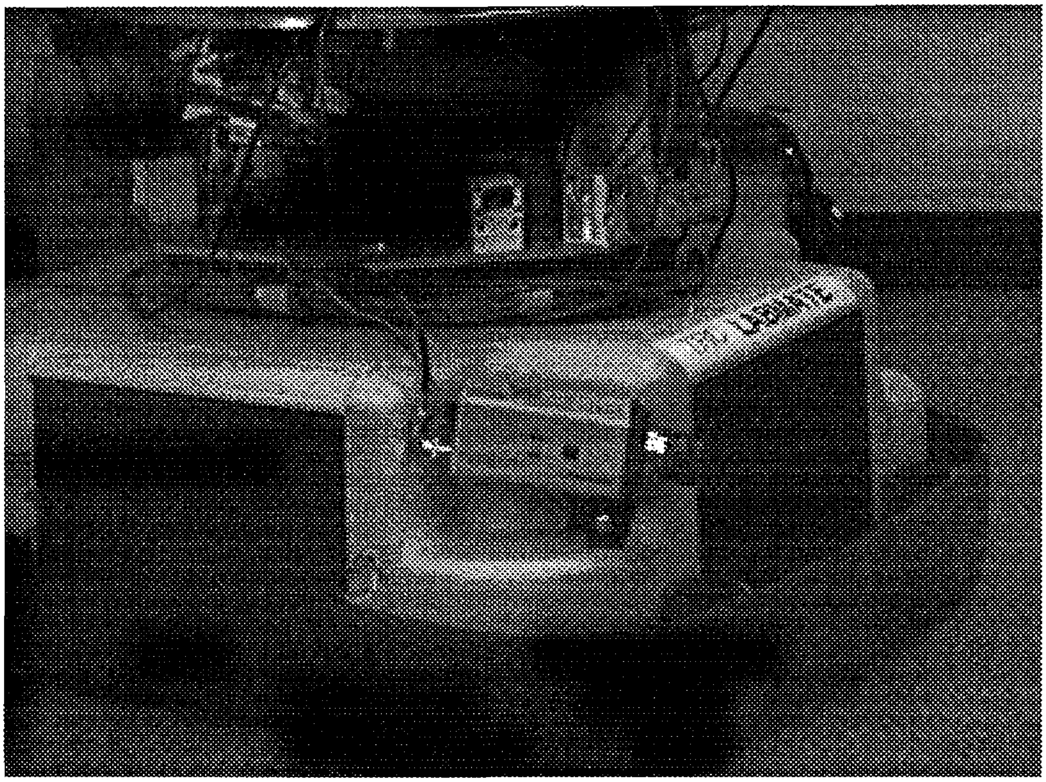

Figure 2.2: Second Camera Mount Location

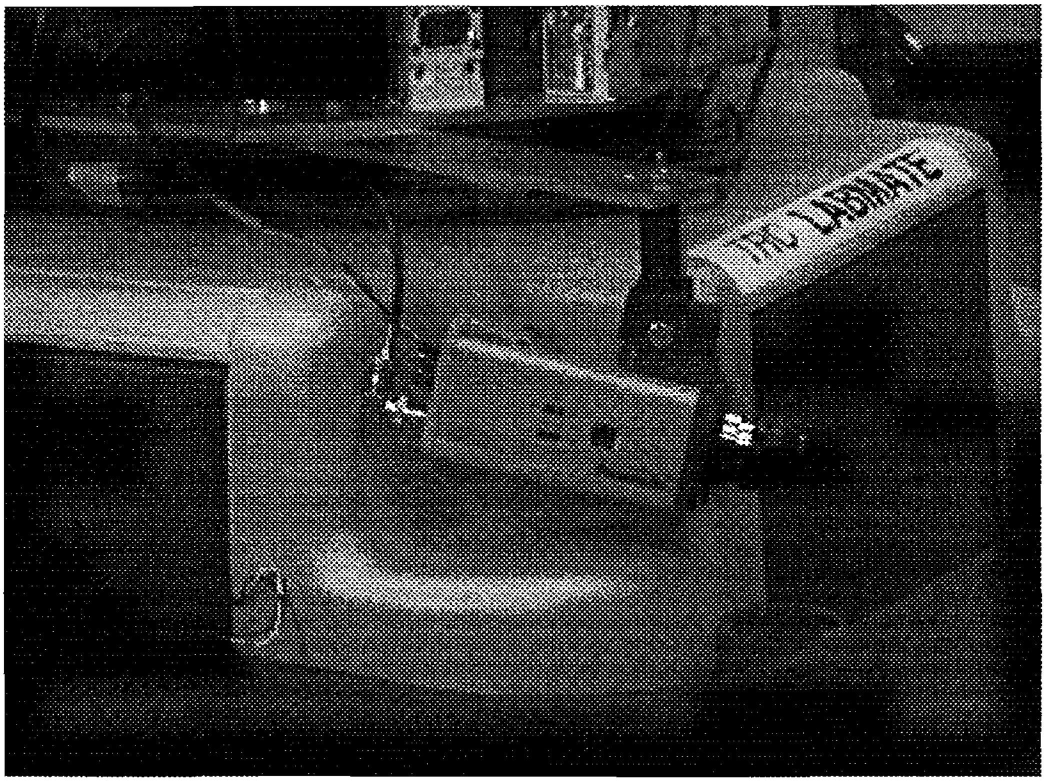

Figure 2.3: Final Camera Mount Location

Chapter 3

Fabrication

3.1 Superstructure

3.1.1 Labmate Mobile Base

The Labmate's framework is constructed mostly out of one-inch steel sections with 10-32 tapped holes in the top members to facilitate bolting down a user-constructed superstructure. Since the holes are concealed by the fiberglass cover, the cover must be removed to determine where the holes are, and then holes must be punched in the appropriate places in the fiberglass cover.

3.1.2 Lower Mounting Plate

We bolted the lower mounting plate, an 18-inch side-to-side octagonal $\frac{1}{4}$-inch aluminum plate fabricated in the College of Engineering Advanced Manufacturing Laboratory (AML), to the Labmate frame through four 3-inch long PVC pipe sections. This 3-inch spacing allowed access to hardware which attached the IR and ultrasonic sensors and a place to coil up the excess IR sensor cable. The two $4\frac{1}{2}$ by 6-inch PCB's of the Proximity Subsystem were bolted to the center of this plate. See Figure 1.1 which shows this initial sensor configuration.

For the final configuration we removed the ultrasonic sensors from the lower plate, repositioned the IR sensors and secured the inverter to the left side.

3.1.3 Upper Mounting Plate

We separated the upper mounting plate, a 22-inch diameter circular $\frac{1}{4}$-inch aluminum plate also fabricated in the AML, from the lower plate with four 7-inch long PVC pipe sections and secured it with $\frac{1}{4}$-inch threaded rods. We bolted the 24 ultrasonic sensor mounting blocks at 15-degree increments on top and near the periphery of this plate. We stacked the three interface boards and one controller board of the Proximity Subsystem and mounted them to the under side of this plate on the right side providing relatively easy access to the serial connector. We taped the eight aluminum brackets used with the ultrasonic transducers when mounted to the lower plate to the top plate to hold the docking station in a stable position.

3.1.4 Camera Mount

After some unsatisfactory camera mount positions (see Section 2.4.3) AML fabricated an aluminum strip for us which was bolted to the lower plate and to which we attached the camera. (See Figure 2.3.)

3.2 UltraSonic Sensor Installation

3.2.1 Sensor Mount Insulation

The first set of 8 ultrasonic transducers which came with the TRC Labmate system included fiber rings to be used as insulation between the transducer and its metal mount to prevent ground loops and false echos. When we decided to add 16 more ultrasonic transducers for the contest, we ordered them from Polaroid Corporation (the primary source) at about one-fourth the price that TRC charged.

However, the transducers from Polaroid did not come with insulating rings and we could not find any local vendors who had anything equivalent. Thus, we had to devise some replacement. Our first thought was to use electrical insulating tape. This was not successful because the tape tended to slip apart after the transducers had been installed causing breaks in the insulation. Finally, we decided to use black nail polish, since it is non-conductive, tough, flexible, easy to apply, fast drying, simple to clean up (with nail polish remover), and easily obtainable. This solution proved to be completely acceptable.

Figure 3.1 shows a front view of the installed transducers with their nail polish insulation and Figure 3.2 shows the view from the back with their connections leading to the interface boards.

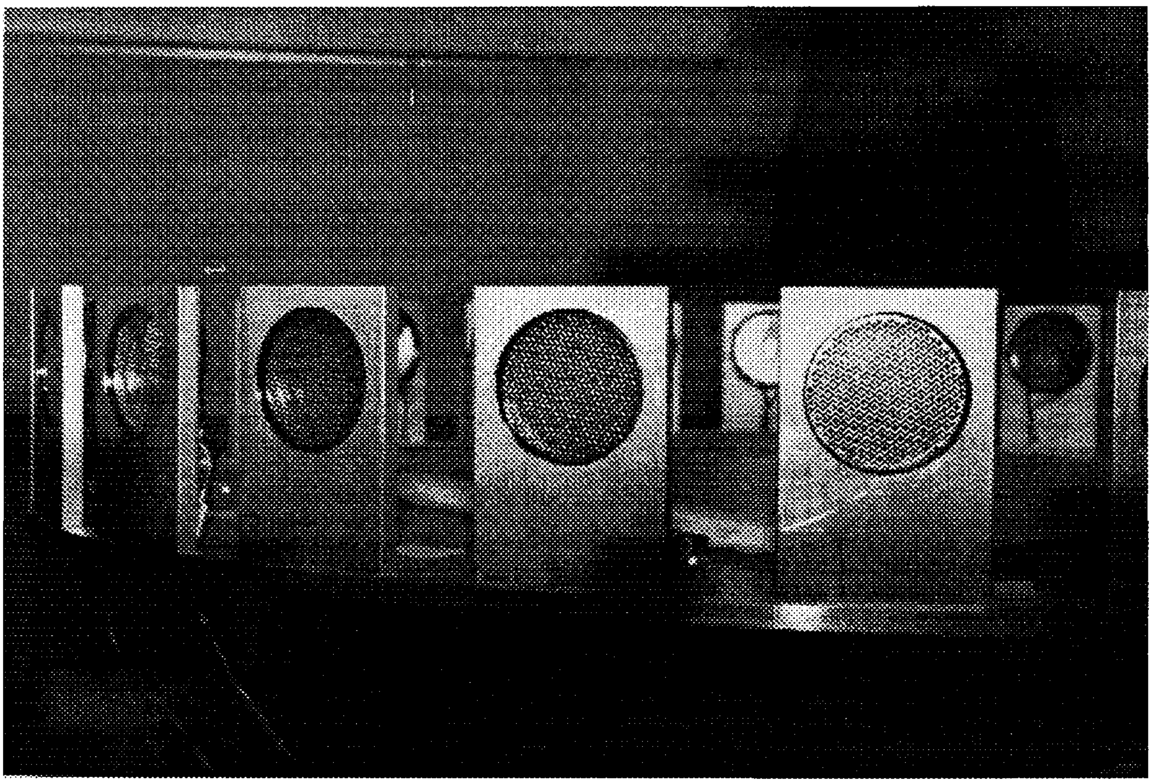

Figure 3.1: Front View of Mounted Ultrasonic Transducers

Figure 3.2: Rear View of Mounted UltraSonic Transducers

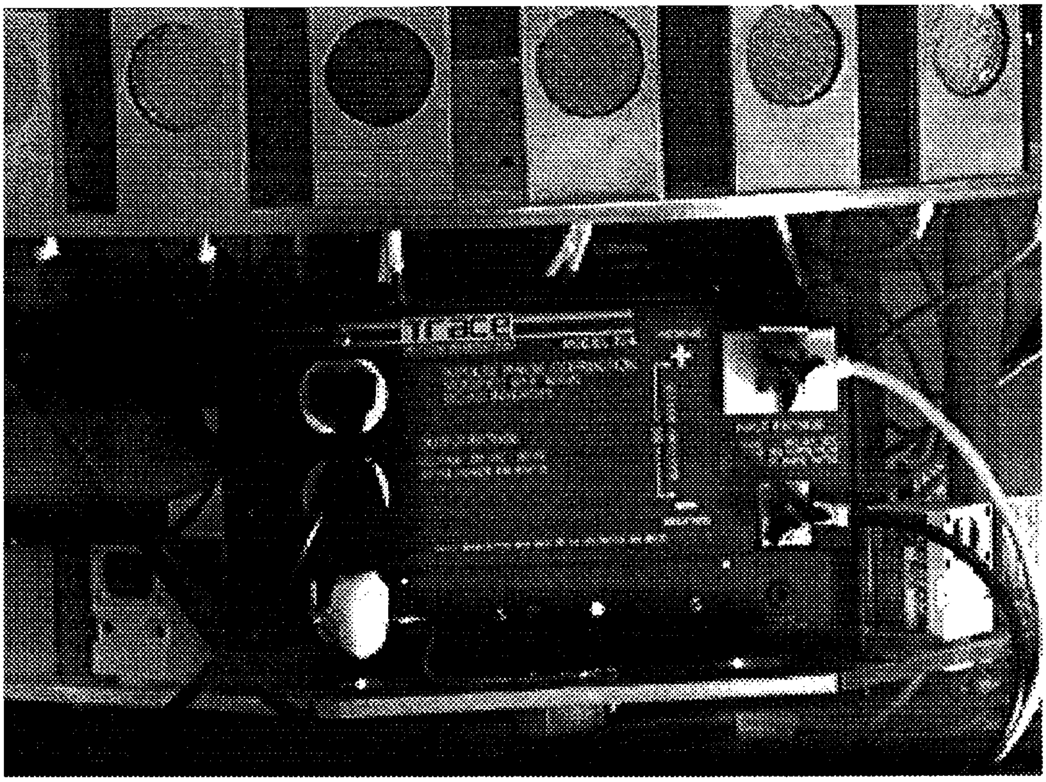

Figure 3.3: Inverter Mounted on Lower Plate

3.2.2 Wiring Diagram

With 24 ultrasonic transducers controlled by three interface boards, we decided to arrange them so that no single board failure would result in complete 'sonar blindness' around one third of the circumference of the Labmate. Thus, we alternated the placement of the transducers from each controller board as shown in Figure 3.4 and described in Table 3.1.

It should also be noted that the order of the controller boards from top to bottom (they are hanging from the top aluminum plate of EGOR) is: Interface Board 0, Interface Board 1, Interface Board 2, and Proximity Subsystem Controller Board.

3.3 Inverter Installation

We bolted the inverter to the left side of the lower plate giving easy access to its on/off switch and the ac outlets. (See Figure 3.3.)

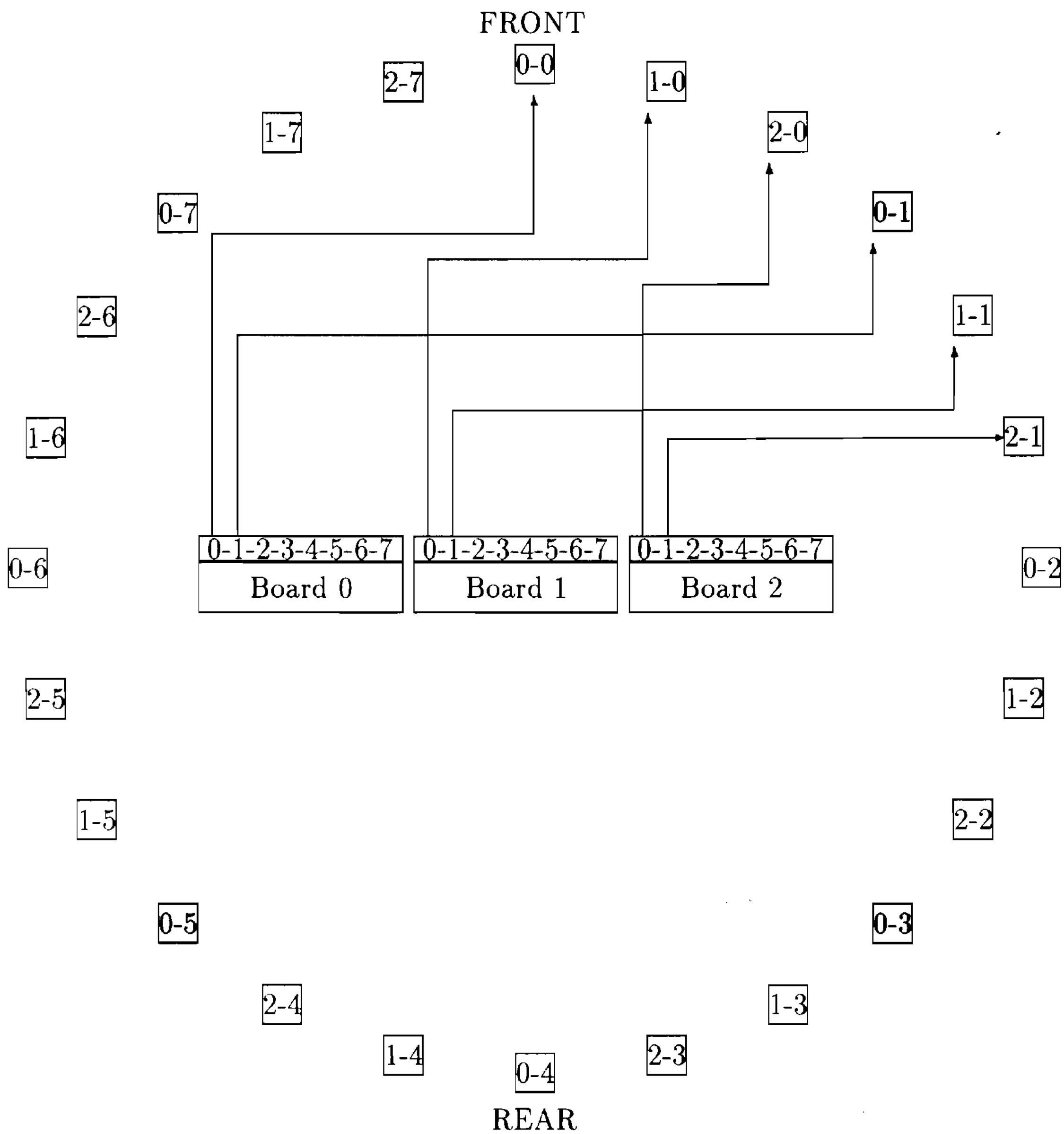

Figure 3.4: Wiring Arrangement of UltraSonic Sensors

Array No.	Board No.	Sensor No.	Heading (deg)
0	0	0	0
1	1	0	345
2	2	0	330
3	0	1	315
4	1	1	300
5	2	1	285
6	0	2	270
7	1	2	255
8	2	2	240
9	0	3	225
10	1	3	210
11	2	3	195
12	0	4	180
13	1	4	165
14	2	4	150
15	0	5	135
16	1	5	120
17	2	5	105
18	0	6	90
19	1	6	75
20	2	6	60
21	0	7	45
22	1	7	30
23	2	7	15

Table 3.1: Wiring Assignments of UltraSonic Sensors

Chapter 4

Software Development

4.1 Modification of TRC Software

The software delivered with the Labmate System was written in C which was reasonably compatible with the Borland 3.1 C which we were using on the Gateway PC for our development. However, the RS232 interface routines (using the PC Com4 and Com3 lines for motor control and sensor control, respectively) were written in assembly language. We soon found out that these routines were incompatible with some other I/O operations (e.g., it was not possible to use the mouse/cursor while using the TRC I/O routines). It was necessary to get information on DOS system calls [28]. With this information, we wrote the interface calls for motor control and sensor controls (as well as additional routines to handle mouse/cursor operations) in Borland 3.1 C using DOS system calls to handle I/O.

At a higher level, we found it useful to modify the routines that input the sensor reports. Originally, the TRC software returned the sensor report information in an array stored by board number (0, 1, 2). That is, all the sensor reports from board 0 were returned in the first eight locations of the array, with sensor reports from board 1 in the next eight locations, and those from board 2 in the last eight locations. However, we arranged and wired the ultrasonic sensors so that the failure of a single board could not knock out all the sensors, as described in Chapter 3, UltraSonic Sensor Installation and shown in Figure 3.4.

Based on this arrangement, the sensor report input routines were rewritten so that the array was filled in the order: 0-0, 0-1, 0-2, 1-0, 1-1, etc. This corresponds to angular locations: 0 degrees, 345 degrees, 330 degrees, 315 degrees, etc., with 0 degrees to the front. In this way, we could address the sensors by index running from 0 to 23. This is described in Table 3.1.

Mode	Name	Condition for Entry
00	Joystick Mode	Labmate reset, *joystick mode* command
01	Go Mode	*go mode* command, on exit from modes 02-08
02	Continuous turn mode	?
03	Point-to-point go mode	*ptp-go* command
04	Point-to-point turn mode	*relative-turn* command
05	Jog mode	*jog-mode* command
08	Proportional go mode	?

Table 4.1: Labmate Modes

4.2 Learning Experiences

As with all new hardware/software systems, our ignorance greatly exceeded our knowledge at first and we were forced to take incremental steps in our development of EGOR. Indeed, we made many false starts and mistakes in the beginning. (Not to say we weren't still making them right up to the contest.)

For example, the initial motor control routines we worked on only attempted point-to-point movement, with location updates considered during pauses between motor commands. Later, we learned to control motion dynamically, while the Labmate was in motion.

4.2.1 Serial Communication Errors

One of the most trying problems we encountered involved getting good status reports from the Labmate motor control system. This type of information includes X-Y position and current heading from the encoders, and Labmate mode. Labmate mode indicates which of eight modes (see Table 4.1) the Labmate is in currently. (Note that modes 06 and 07 are undefined.)

The problem manifested itself when the *get report* command was issued while the software was executing loops. (For example, while waiting for a point-to-go to be completed, the *get report* command is issued to determine when the Labmate changes from *point-to-go mode* to *go-mode*. Strangely, *go-mode* indicates a cessation of movement when certain parameters are zero.) Unfortunately, by checking another parameter (*LABMATE-status*), we discovered that we were not getting accurate encoder information due to communication errors on the RS232 COM line.

After much experimentation, we found that the *get report* commands could not be issued more often than five to six times per second. When the code was corrected to reflect this limitation, we were able to obtain reliable encoder information consistently.

4.2.2 Encoder Errors due to Slippage

One of the difficulties we encountered was encoder error (especially in heading) after Labmate turns. As an example, we commanded the Labmate to turn in place to the right (clockwise) 180 degrees, and then turn back to the left (counter-clockwise) 180 degrees. The labmate should then have been facing in the same direction that it started. Instead, we found errors of several degrees in its heading. Sometimes these errors amounted to more than five degrees. This size of error could be disastrous if allowed to accumulate for very long.

After investigation, we found two conditions which contributed to these types of errors. One was the type of surface on which the Labmate was being tested. The indoor carpeting in the Vision Lab caused slipping of the wheels which could not be corrected, no matter what we tried. In addition, we found that (even on good surfaces like the tiled hall floors) high speed turns led to slippage errors in heading. This was alleviated by limiting the speed of the Labmate on turns. (See also Section 6.2.)

4.2.3 Ultrasonic Sensor Timing Considerations

During experimentation with the ultrasonic transducers, we found (not surprisingly) that the timeout distance (which is set by software) controlled the update rate of the sensor reports. That is, the shorter the timeout distance, the more rapidly the sensor reports were received.

The Labmate ultrasonic sensors can be assigned to two different cycles, primary and secondary. All the sensors in the primary cycle fire in sequence and then one sensor in the secondary cycle fires. Then all the sensors in the primary cycle fire, then the next sensor in the secondary cycle fires.

The combination of controlling timeout distance on individual sensors and assigning different sensors to primary and secondary allowed EGOR to be able to look down the hall for obstacles, while at the same time keeping close watch on the side walls to keep straight and look for doors.

4.2.4 Mode Switching for Smooth Stops and Starts

Labmate provides two variables that the user can set for velocity. Different modes use these velocity settings in different ways. If the user changes the velocity which is currently being used there will be a noticeable jerk. However when the user changes modes, one mode using one velocity setting and the other mode using the alternate velocity setting, the Labmate will make the transition smoothly at a constant acceleration.

4.2.5 Simultaneous Walking and Talking

A post-mortem analysis of the last run of Event 1 of the mobile robot contest revealed a problem when reading a .voc file for voice. While Egor was saying, "Walk this way" he missed a crucial doorway. The obvious, though belated solution, of course, was to talk *before* walking, not during.

4.3 Additional Interface Software

In addition to the modifications to TRC software mentioned above, we found that several more interface procedures were needed in dealing with the ultrasonic sensors.

4.3.1 Reading Ultrasonic Sensor Distances

When reading sensor data a procedure is called which fills a 24-element array with distances read from each individual sensor. In practice however, only a few will have valid distance information due to inherent time delays and other factors. To deal with this we wrote procedures that returned selectable values to indicate no distance measurement available.

4.3.2 Prioritizing Sensors

When reading distances from a ring of 24 ultrasonic sensors, one quickly learns that if all 24 are turned on a valid measurement from any one sensor is received only once every 3 or 4 seconds. Therefore prioritizing is necessary. We wrote a procedure that helps in this by specifying sensors using a bit pattern for each of the three boards for each of the two priorities.

4.3.3 Setting Timeout Distances

In the dynamic world of a mobile robot where ultrasonic distance measurements must be timely, setting the timeout distance for each of the critical sensors is important. Individual sensors or groups of sensors may be reset to a new timeout distance with a procedure we wrote for this purpose.

4.3.4 Procedural Example

To illustrate how these procedures might be used, consider the problem of traversing a hallway. Sensors 6 and 18 (see Figure 3.4) would be made the primary sensors for wall following and door sensing. Sensors 23, 0 and 1 would be made secondary sensors for detecting obstacles. The primary sensors would receive valid data every cycle at 4 to 5 cycles per second. Each secondary sensor would receive a valid measurement about every third cycle. The timeout distance for sensors 23, 0, 1 would be set to 2000 mm, probably adequate for detecting obstacles when moving at 100 mm/sec. After reading the wall distances for a period, the timeout distances for sensors 6 and 18 might be set separately to that distance plus 500 mm. Upon detecting the sought doorway or hall junction or upon detecting and verifying an obstacle a whole new observation and behavior regimen is entered.

Chapter 5

System Evaluation

5.1 Labmate Mobile Platform

The Labmate mobile platform, which was already in house when the decision to enter the AAAI contest was made, has proved to be a very robust system. It lent itself well to additional weight and the two twelve volt batteries have handled the additional electrical load of the inverter, the computer and docking station, and the video camera.

However, as has been implied elsewhere, the motor commands could not be considered the most "user friendly." For example, the differences between the various modes (see Table 4.1) was not at all clear and their proper use had to be determined empirically.

5.2 UltraSonic Sensors

The Polaroid ultrasonic sensors were completely satisfactory. We found that they could give repeatable results to within a few millimeters. They were also quite robust and none of them failed or showed any faulty returns during the seven months that the system was in development.

However, they exhibited the same limitations that are characteristic of ultrasonic transducers in general – indirect returns when hitting surfaces at an oblique angle and uncertainty in direction due to the spread of the sensor beam. The indirect returns resulted in erroneous distance measurements (too far to surfaces) and the beam spread caused objects to appear larger than they were and openings to appear smaller than they were.

Although the transducers did not fail during the development period, we did have some problems with the TRC ultrasonic sensor controller board during the contest. It failed with all sensors showing maximum returns. We were able to get around the problem by turning off the sensor system, letting it cool off for a few moments, and turning it on again. It appeared that some combination of conditions may have put the controller board in this state, but we were not able to verify this due to the intermittent nature of the problem.

5.3 IR Sensors

The infra-red sensors were somewhat of a disappointment. Although we knew that they could only provide binary information, we found in addition that their sensitivity could not be set and calibrated for distance with any reliability. We attempted to set them so that they would provide final collision warning. That is, we wanted them to respond only to objects within a few inches in front of the sensors. When we tried to control their sensitivity we found it varied by one foot or more immediately after we had set them. Since we could not afford to have collision warning halts when objects were still a foot or more away (we had to pass through doorways with less than an inch clearance on either side), we were forced to abandon their use for the contest.

5.4 Computer and Docking Station

The DFI laptop computer, in conjunction with the docking station, proved satisfactory. It was robust, easy to use, and naturally, very handy since the laptop itself could be removed from the system ('taking out EGOR's brain') and interfaced with other PC's to copy files and use it for off-line work.

The docking station was also very handy. It was very convenient to add the various standard PC interface boards in the 16 bit ISA slots (sound, video digitizer) and it also provided the additional RS232 serial ports (COM lines) which we needed to interface with the Labmate motor controls and ultrasonic sensors.

5.5 Sound System

The Creative Labs Sound Blaster System provided EGOR with a magnificent Slavic voice to announce his intentions. With the add-on speakers, his voice could be easily heard in the contest arena.

5.6 Voice Recognition

The Microsoft voice recognition system proved to be a disappointment. The sensitivity of the system could not be adjusted to eliminate interference from the ultrasonic transducer relays which produce an audible *click* (the transducer frequency was too high to be picked up by the system). In addition, the voice recognition was not consistent. It easily confused words with consonants (*left, quit*) and also went into shock when there was background noise. Since the contest was to be held in an arena with many (vocal) spectators, we felt it was too risky to use.

5.7 Video Digitizer

The Hauppauge Win/TV digitizer board was satisfactory. In addition to the digitizer board (which came with software to display the video picture live in Microsoft Windows), we also bought the Hauppauge Programmer's Toolkit, which included C callable routines which were used in the Event 2 software to access the digital images collected by the digitizer board. All the Hauppauge hardware and software worked as we had hoped it would. We did have some trouble with the digitizer board when we first installed it, but we called Hauppauge, and they provided on-line trouble-shooting assistance. We thereby discovered the board was faulty, returned it to Hauppauge and received a good board within a week. We received very good technical support from Hauppauge.

5.8 Camera

The Panasonic video camera from TV Specialists worked as was expected. However, the field of view was less than we had expected, but apparently, wide-angle lenses are not considered acceptable for image processing.

5.9 Compilers

The compiler which we first began to use was the Borland C/C++, version 3.1. This compiler did not support concurrent processing, nor did it support Windows programming. We ordered the Borland C/C++ 4.0 Compiler, but we found it took up so much additional memory that we decided to stick with the 3.1 version. This worked out quite well, although concurrent processing would have been preferable.

5.10 Overall System

The results of the AAAI Competition demonstrated foremost the immaturity of our hall-following software. The get-out-of-the-room (Event 1) software performed adequately but consumed more time than desirable. From this experience we learned that a successful robot entry must have a good selection of well-tested behavior procedures and upon arrival at the competition site, one must tailor the software to handle the unanticipated situations and get as much testing in as possible before and between the scored trials. At the 1994 AAAI Competition we were somewhat overwhelmed by unanticipated situations. This, of course, would not be the case in the future.

The hardware, on the other hand, proved quite robust. We experienced no mechanical problems and only the one electrical problem with the sensors which did not affect the competition. The sensor configuration seemed perfectly adequate for the competition environment. Aesthetically, EGOR was outclassed by many of the other entrants, but luckily appearance was not scored.

One limitation of the hardware implementation was the lack of computing power for image processing. The 486DX33 CPU was never expected to handle very much in the way of real-time image processing. While the Win/TV can handle digitizing at rates up to 60 frames per second, the CPU was much too slow processing those images. In future, if real-time image processing is desired, it would probably make sense to install the Datacube on EGOR (see Section 7.2.3).

Chapter 6

Operational Information

6.1 Battery Experience

The two sealed lead-acid batteries that provide portable power for the Labmate and inverter are rated at 30 amp-hours. This capacity characteristically falls off with age. During testing in the hallways of the third floor of the MEB we continuously monitored battery voltage since the inverter had an automatic cutoff at 23.5 volts. Should this happen while the Labmate was in motion the laptop computer would lose power, no further commands could be issued and the Labmate could only be stopped with bumper contact or by manually hitting the motor power switch.

To help alleviate the problem of diminishing battery capacity we purchased fresh batteries and installed them just prior to the contest. We also altered our testing regimen by plugging in the battery charger during extended periods of data analysis and software modification on the laptop computer.

6.2 Drive Wheel Pressure Adjustment

The weight of the Labmate and its payload is distributed between two drive wheels and four corner casters. Screw adjustments can be made to put more of the weight on the drive wheels. The Labmate Users Manual [24] suggests that this be done as the payload is increased to reduce drive wheel slippage. We did this but the results were at best marginal. In general slippage can be reduced using lower speeds and judiciously changing modes.

Chapter 7

Future Developments

7.1 Capabilities

7.1.1 Mobile Platform with A/C Power

The Labmate mobile platform can provide a convenient test bed for a wide variety of experiments and study. Payloads up to 400 pounds and speeds exceeding 1 meter per second can be accommodated. The inverter provides 110 vac up to 700 watts. We hope this mobile robot capability will challenge and amuse CS students in the future.

7.1.2 UltraSonic Sensor Capabilities

> ...when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind.
> *William Thompson, Lord Kelvin*

The Polaroid ultrasonic transducers give us a good measurement tool. The TRC controller provides a good deal of flexibility using up to 24 sensors in an echo ranging mode. A wide range of other modes can be envisioned, a few of which are mentioned below. These would require some engineering and probably programming a microprocessor but should be within department capabilities. These transducers are relatively cheap (about $10 each) and all of the other parts needed for drivers, controllers, interfaces, etc., are inherently inexpensive.

7.2 Possible Projects

7.2.1 From Simulation to EGOR

Currently, Alyosha Efros is developing a simulation of EGOR's sensor and motor systems which would fit neatly into a beginning course on mobile robot navigation. Programs could be first checked out on the simulation, then tested on EGOR.

7.2.2 'Smart' Sensors

Mohamed Dekhil is working on providing 'smart' sensors for EGOR, which will allow programming logical behaviors for EGOR in which different physical sensors can be used as replaceable parts with the same logical interfaces.

7.2.3 Real Time Vision with Datacube

The image flow processing of Datacube could be well exercised by mounting it on a mobile platform. Provision would have to be made for inserting a processor in the VME bus for untethered mobility. If umbilical cables could be tolerated for an initial configuration, only TV cameras need be mounted on the mobile platform.

7.2.4 Manipulator Arm on EGOR

EGOR with a robotic arm (and better vision) would certainly make an impressive entry in robot competition. Such an ambitious project would require much dedicated work over an extended period of time.

7.2.5 'Robat II'

The remarkable ability of the bat's use of echolocation presents an interesting challenge. In the work done by Barshan and Kuc [4], one transmitter flanked by two receivers were used to simulate prey capture of a simulated robot moth. However, studies done by Elisabeth K.V. Kalko [30] seem to indicate that bats use much more than just the echo envelope to track and catch prey. Apparently, echolocation signal patterns emitted by bats are tailored in frequency depending upon whether (among other things) they are searching for food or homing in on that food. The conclusion is that bats are capable of interpreting the doppler shifts resulting from moving targets. This is not so strange as it might seem. Humans easily handle the doppler shift of approaching versus receding trains, for example. Adding this type of processing to a bat-like transmitter/receiver system should not be impossible, especially if an FFT (Fast Fourier Transform) chip were added to handle the analog input signal coming in to the transducer. While one cannot compare hardware processing power directly with the "wetware" processing power of the bat, with its distributed processing, EGOR can carry a lot of processing power and the bat's brain is pretty small.

7.2.6 Tracking Range

A concept used in underwater test ranges for tracking vehicles could be applied to a large indoor area using the ultrasonic transducers. Receiver transducers could be mounted in the ceiling, their positions measured and connecting cables laid to a central controller board and computer at a fixed location. At regular intervals, say once per second, a radio signal would trigger a chirp from a transmitting transducer on the mobile robot. The measured arrival times of the chirp at the several receiving transducers could be used to calculate the robot's position within a few millimeters. This seems to be a relatively cheap solution to one of the common problems in robot navigation.

Chapter 8

Vendors and Contacts

8.1 Labmate and IR Sensors

The Labmate and IR sensors are built by:
Transition Research Corporation
15 Great Pasture Road
Danbury, Connecticutt 06810
Phone: (203) 798-8988
Fax:.. (203) 791-1082
Contact: Stuart Lob, Ext. 339

8.2 Additional UltraSonic Sensors

Additional polaroid ultrasonic sensors can be purchased as follows:
Item name: Ultrasonic transducer
Part No.: 616342
Polaroid Corporation
5601 Fulton Industrial Blvd.
Atlanta, Georgia 30378
Phone: (800) 225-1000

8.3 Laptop and Docking Station

The DFI laptop and docking station were purchased from:
Item Name: DFI Notebook Computer
Part No.: 486DX33 w/ 4MB RAM, 200MB Harddrive
Office Equipment Associates
1357 South Main Street
Salt Lake City, Utah 84155
Phone: (801) 467-6537 or
Phone: (801) 485-1781
Contact: Larry Johnson

8.4 Microsoft Voice Recognition

The Microsoft Windows Sound System was purchased from:
Item name: Microsoft Windows Sound System with 16-bit Sound Board
Part No.: 206-050-V100
California Digital
17700 Figueroa Boulevard
Gardena, California 90248
Phone: (800) 421-5041
Fax:.... (310) 217-1951

8.5 Sound Blaster Sound System

The Creative Labs Sound Blaster was purchased from:
Item Name: Sound Blaster 16 Audio Card
Software, ETC.
Valley Fair Mall
West Valley City, Utah
Phone: (801) 963-9918

8.6 Panasonic Video Camera

The video camera purchase information is:
Item Name: Panasonic Video camera
Part No.: WV-BP102
TV Specialists, Inc.
Video Systems Division
180 east 2100 South
Salt Lake City, Utah 84115
Phone: (801) 467-6537
Contact: Dick Gorman

8.7 WinTV Video System

The Win/TV digitizer system purchase information is:
Item Name: Video Capture Board
Part No.: Win/TV-00
Item Name: Programmers Toolkit
Part No.: Win/Tv-TK
Hauppauge Computer Works
91 Cabot Court
Hauppauge, New York 11788
Phone: (800) 443-6284
Contact: George, Ext. 301

8.8 Trace Engineering Inverter

The inverter purchase information is:
Item Name: Trace Inverter, 24-volt, 700-watt
Part No.: 724
Solar Electric Specialities
9514 S. David Street
Sandy, Utah 84070
Phone: (801) 751-0643
Fax:.... (801) 572-2304
Contact: Orrin Farnsworth

8.9 PowerSonic Corporation Batteries

There are two extra batteries for EGOR in the Vision lab. Additional batteries can be purchased from:
Item Name: PowerSonic Corporation Sealed Battery
Part No: 12600 12 Volt Battery
Standard Batteries
1506 S. Redwood Road
Salt Lake City, Utah
Contact: Lance

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