Mobile Robots and Interdisciplinary Design - MOBOTS

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Abstract

An engineering curriculum challenge is to create an environment in which engineering problems can be solved using different strategies or variations to a common approach and that has a team component. This paper discusses the construction of Mobile Robots (MOBOTs) in the Electronic and Electrical Engineering undergraduate robotics laboratory of California State University, Sacramento that contains interdisciplinary engineering design. The course is open to all engineering and computer science students with a sufficient background. The MOBOT is composed of a based mobile platform (Brawn) driven by two motors on which is mounted an embedded microprocessor board with various sensors (Brain). Interactive C (IC), developed at the MIT Media Lab, is used to program the MOBOT for autonomous operation and non-autonomous tests. During the lab periods, MOBOT teams are formed to construct the MOBOTs with the major objective of competing in the MOBOT Olympic Games at the end of the semester.

Introduction

The main focus of the Robotics Laboratory is to provide a "systems" experience for the students by having them construct a Mobile Robot (MOBOT) on which are various sensors, steering motors, power, and an embedded microprocessor and which can operate autonomously by executing downloaded IC code. IC was developed at the MIT Media Lab by Randy Sargent with assistance by Fred Martin. Newton Labs at *http/www.newtonlabs.com/* on the web has extended IC.

Two students are assigned a MOBOT to construct. If there is an odd number of students in the course, three students will be assigned to construct a MOBOT. This paper describes the activities performed by the students during the lab periods which are to 1) construct the mobile platform for the MOBOT to familiarize them with mechanical components such as motors, wheels, gears, and gear ratios, 2) mount the MOBOT Brain on the MOBOT Brawn platform that includes light-sensing photo resistors, bumper switches, sound-sensing microphone and motor-driver circuitry, and a MC68HC11 system with a LCD, 3) determine the maximum MOBOT carrying capacity, maximum ramp slope for the MOBOT, and torque/speed curve for the MOBOT motors, 4) write IC code to test and obtain data that characterizes each sensor, 5) design and implement in IC, MOBOT steering and speed control algorithms and 6) design and implement a strategy to compete in the MOBOT Olympic Games. The paper concludes with a discussion on the impact of requiring student MOBOT teams to compete with their MOBOTs.

Brawn

The first laboratory task is for each MOBOT team to construct the MOBOT Brawn which is the mobile base with motors. A bulldozer kit, shown in Figure 1, made by the Tamiya Plastic Model Co., Shizuoka-City, Japan, is modified so that the batteries and brain (microprocessor board) can be placed on top of the mobile base.

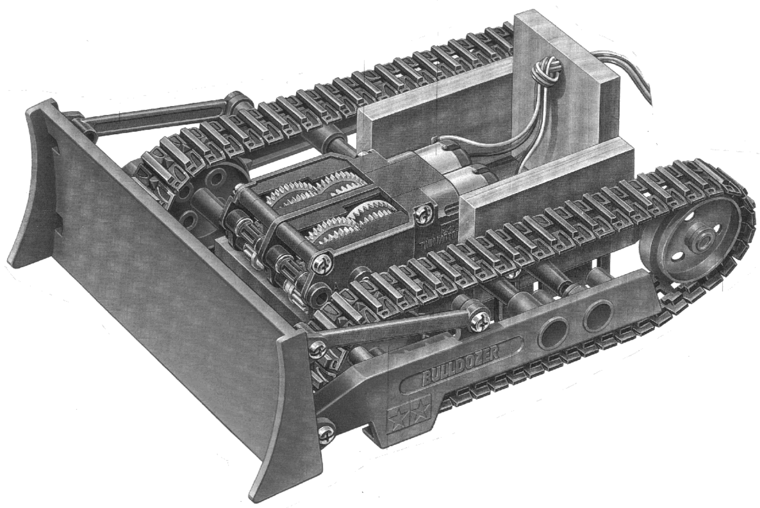

Figure 1. Bulldozer kit used to construct the MOBOT Brawn

The bulldozer kit shown in Figure 1 can be purchased from the Mondotronics Robot Store Catalog web site, *http://www.robotstore.com/catalog.html*, under Hackable Robot Kits for $39.95. The vertical wood piece is cut so that it is flush with the side wood pieces and the dozer blade in front is removed and replaced by a front bumper with bumper switches. After modification, the Brawn is approximately 4.5 cm high, 10 cm wide and 14 cm long. At the end of each semester, the MOBOT is disassembled including the gearbox. The students are required to reassemble the Brawn so those students become familiar with the mechanical components, gaining an understanding of how the gearbox operates and how the motors drive the wheels.

The students perform experiments to determine the maximum carrying capacity of the Brawn and motor torque/speed curves. The following is a summary of the tasks that the students perform using only the Brawn [1, 2].

<u>Basic Measurements</u>: Perform the following: 1) record the gear ratio, wheel radius dimension in meters, size and weight, 2) sketch the gear assembly for the motors, 3) determine the gear ratio from motor shaft to the load shaft and 4) weigh the unloaded (no batteries or brains on the MOBOT) MOBOT.

Unloaded Brawn Experiment: Using the control unit supplied with the bulldozer kit, control the movement of the modified Brawn to: 1) record the time the unloaded MOBOT takes to traverse three meters at a reasonably constant velocity using the wall clock or a stop watch and 2) measure the current and voltage delivered to the motors under this unloaded condition.

Loaded Brawn Experiment: Using the control unit supplied with the bulldozer kit: 1) place about one pound on top of the constructed Brawn and record the weight of the loaded MOBOT, 2) record the time the loaded MOBOT takes to traverse three meters at a reasonably constant velocity using the wall clock or a stop watch and 3) measure the current and voltage delivered to the motors under this loaded condition.

Stalled Motor Experiment: Firmly hold the wheels so the motors will not turn when power is applied and measure the current and voltage delivered to both motors when both motors are kept from rotating (measure the voltage at a point after the current meter).

Torque-Speed Plot: Use the collected data above to:

1) compute the effective motor armature resistance,

$$R_a = \frac{V_{STALL}}{I_{STALL}} \quad Ohms,$$

2) using data from the loaded Brawn experiment, compute the torque constant,

$$k_i = \frac{V_{Loaded} - I_{Loaded}\, R_{Loaded}}{\omega_{Loaded}\ (r/s)}$$

3) compute the Stall, Loaded and Unloaded Torques supplied by the motors using,

$$T(Nm) = \frac{k_i * V(Volts) - k_i^2 * \omega}{R_a(Ohms)}$$

4) sketch the Torque versus Wheel Speed (r/s) curve using the three points.

Maximum Slope for Loaded MOBOT: Estimate the maximum slope, θ_{MAX}, that your loaded MOBOT can climb. Include equations to support your results. Hint: Calculate the rolling friction coefficient, C_t, using the Loaded MOBOT data and the maximum mechanical power, P_{m_max}, point [1, 2].

Battery Life: Estimate the length of time that your loaded MOBOT will run on a flat surface using four AA rechargeable batteries. Include equations to support your results.

Brain

The Brain, a component of the "Rug Warrior," was purchased from A K Peters, Ltd., whose web site is *http://www.akpeters.com/*. The present cost of a Brain is $359. The basic concept of the Brain was first formulated in a book by Joseph Jones, Anita Flynn, and Bruce Seiger entitled *Mobile Robots: Inspiration to Implementation* [2]. The Brain is a printed circuit board that contains an embedded MC6811 microprocessor system and LCD and proximity IR sensors, light sensing photo-resistors, bumper switches, sound sensing microphone, motor shaft encoders, motor driver H-Bridge and a serial connection to a PC [3,4]. The sensors are discussed in Sensors and Motor Tests section. This board was chosen because of its functionality and ability to run IC, Interactive C, that comes with the board. Furthermore, IC comes with software drivers for the motors and for all of the sensors on the board [4,5].

The Brain and two battery holders, each containing four AA rechargeable batteries, are mounted on the Brawn. One set of batteries is used to power the motors and the other set is used to power the microprocessor system. The outputs of the Brain H-Bridges are connected to the motors via connectors on the Brain board. One of the connectors on the Brain board supplies power from a six-volt battery pack to the motors and the other connector supplies power to the microprocessor system and sensors. Communication is established between a PC and the Brain board via a 9600 baud serial communication link. Tests are performed by running IC in DOS mode. That is, IC is an interpretive "C" environment, which permits "C" statements to be executed line by line at the DOS prompt. IC programs can also be written using a text editor on the PC and sent to the Brain for execution, which permits autonomous mode operation of the MOBOT.

Sensors and Motor Tests

One of the advantages of using IC is that the software drivers for the sensors that come with the Brain board have already been written and the driver code can be examined by the students. Infrared proximity sensors, even though available, were not used because of other activities planned for the lab time. In addition, the incremental shaft encoder scheme provided with the Brain board was not continued because reliable operation could not be achieved. Plans are to use a more robust wheel position encoder scheme in the future. The following is a brief description of the sensors mounted on each MOBOT and the tests that the students perform:

Photocells: Light-detecting phototransistors are mounted on the left and right side of the Brain board. IC programs are written to characterize the response of the left and right photocells to a bright light under room lighting conditions for distances at 0.1m to 3m from the bright light.

Microphone: A small microphone is mounted on the Brain board. A microphone voice response test is written to gather time-response data to the words "GO" and "STOP." The time-response data is plotted versus time, a frequency analysis is performed using MATLAB, and the data collected.

Bumper: A wood bumper and switches are mounted on the front of the MOBOT. The front bumper is suspended by two switches on the left and right of the MOBOT. Connectors are provided on the Brain board. A resistive ladder network is used to provide different voltages to the analog-to-digital converter of the microprocessor, depending on which switch is open or closed. An IC program is written to determine the voltages generated when one or more switches are closed.

Motors: IC motor tests are written to characterize autonomous straight-line and turning movement of the MOBOT at various speeds. For example, MOBOTs will not, in general, move in a straight line when given the same velocity commands, since feedback velocity or position control is not used at this time.

Figure 2 is a photograph of "Suzie," a complete MOBOT with the Brawn, Brain and sensors.

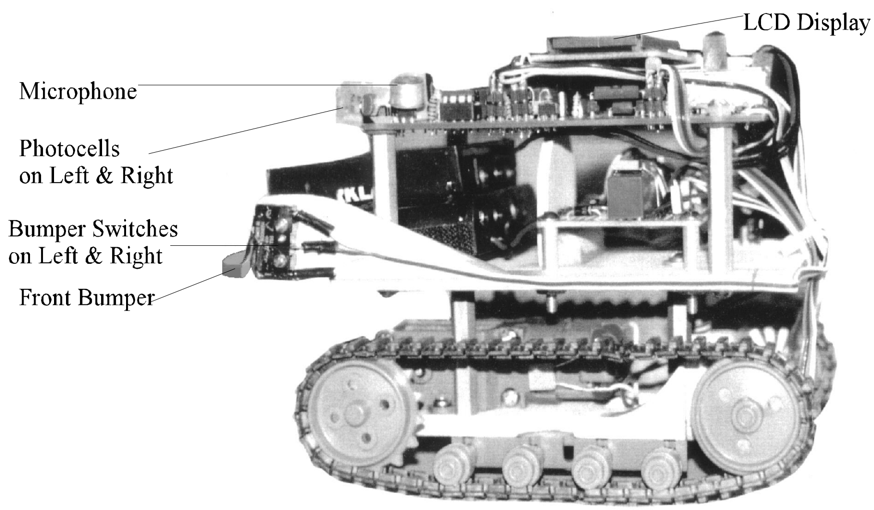

Fig. 2. Suzie the MOBOT

MOBOT Olympics

The MOBOT Olympics is held of the end of the semester. Each MOBOT team designs and implements a strategy to track the horizontal movement of a bright light and to close on it starting at three meters from the bright light source that is placed on the floor. The autonomous MOBOT that reaches the moving light the quickest wins 1st prize. Each MOBOT must be started by pronouncing the word "GO" and stopped when the word "STOP" is pronounced. Hence, students must apply the sensor and basic motor control knowledge they obtained earlier to develop a MOBOT control strategy to track and acquire a horizontally moving light. First Place, Second Place, Third Place and Honorable Mention ribbons are awarded.

Conclusion

Construction of MOBOTs and entering them in the MOBOT Olympics is only one activity performed by the students during the semester lab period; hence, the complexity of a MOBOT and the MOBOT Olympic rules are bounded in order to acquaint the student with image processing concepts and programming of an industrial grade IBM 7040 robot. However, even with the approach chosen, students are exposed to interdisciplinary design concepts by virtue of having to understand and integrate the mechanical, electrical and computer engineering components of the MOBOT. Furthermore, constructing a MOBOT requires team effort and competition among the MOBOT teams. As a result, the students are presented with a problem that requires using different strategies or variations to a common approach.

Unfortunately, many students spend too much time in preparing their MOBOT for contest and neglect their other studies. On the other hand, students generally have few opportunities to be exposed to situations where cooperation is required "to get the job done" and they have fun doing it.

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Mahlon Heller is presently a Professor of Electrical Engineering at California State University, Sacramento (CSUS). Dr. Heller received his Ph.D. in Electrical Engineering from the University of Nevada, Reno. He teaches a series of robotics and machine intelligence undergraduate and graduate courses at CSUS. Professor Heller is actively involved with research that employs undergraduate and graduate students. His current research project is entitled "Research and Development of an Autonomous Shadow Vehicle." Shadow vehicles are used to protect freeway maintenance workers. He also has extensive industrial experience that includes the design of large-scale hybrid simulators and the design and development of one of the first high-speed laser printers for mainframes.