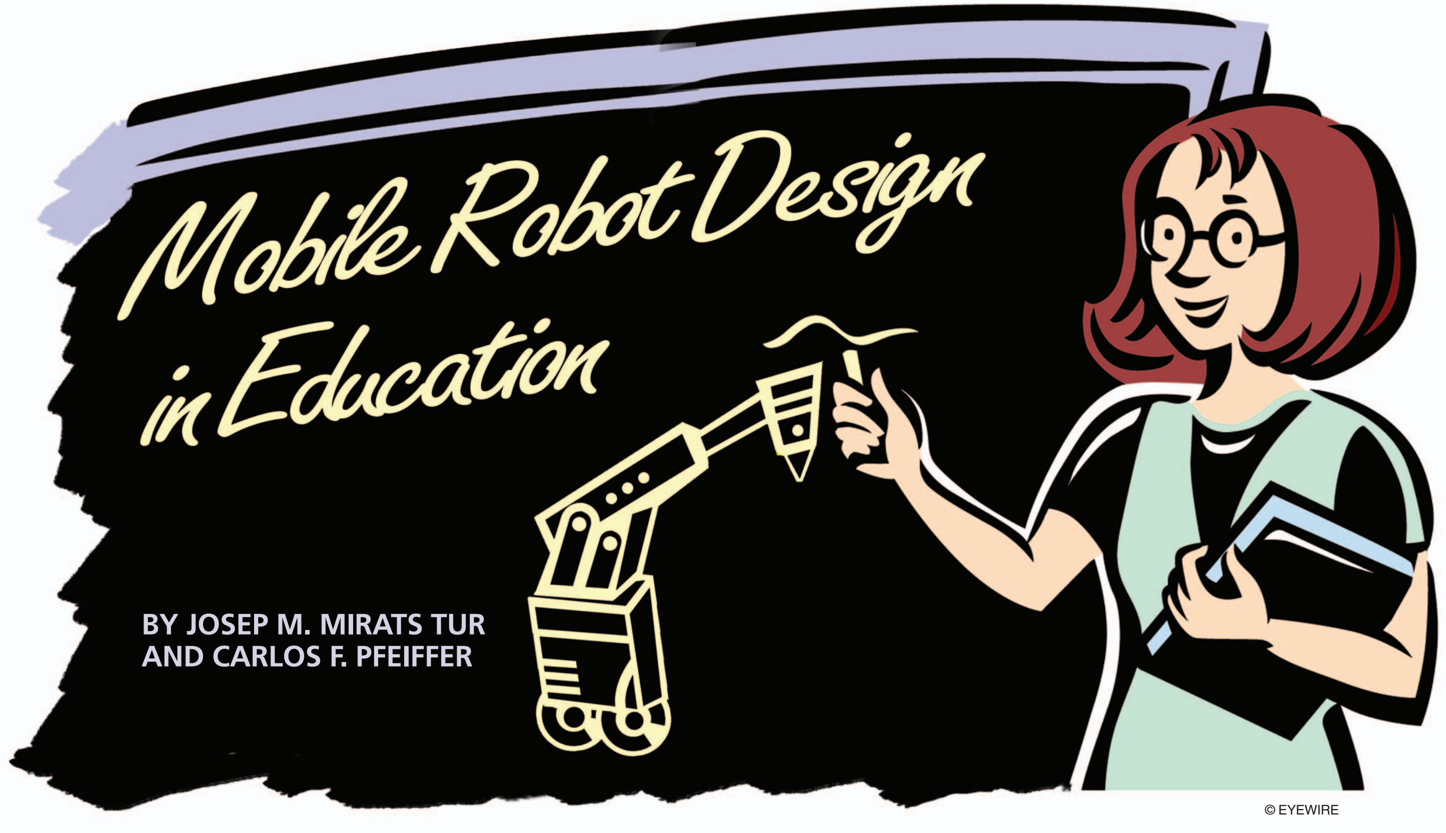
A Modular, Low-Cost Platform

Mobile Robot Design in Education



BY JOSEP M. MIRATS TUR AND CARLOS F. PFEIFFER

Mobile robotics is still an open and challenging field with a big future, having many possible indoor as well as outdoor applications that can help to improve industrial production and some aspects of workers' quality of life [1]. Very interesting applications are being developed that, in the medium term, can be part of our daily lives [2]. Nevertheless, most of these applications are still in the research stage; it is important that the knowledge generated by those research efforts is gradually incorporated to the topics that students, mainly engineers, learn in universities, bringing together the research and student communities.

Therefore, robotics itself can be used not only for industrial improvement but also for education purposes. Nowadays, it is of the maximum relevance that computer, electric, control, or mechanical engineering university program studies include the teaching of both theoretical and practical courses on robotics. While traditional technical education strategies tend to promote individualism and competence among students, nowadays, engineering challenges in most areas, and especially robotics, require working with multidisciplinary teams in order to successfully integrate different areas of knowledge. Practical work on robotics at the university level can help engineering students develop the needed communication and working skills for teamwork.

The purpose of this article is twofold. First, we briefly describe the course on robot design that electronics systems engineers take in their last semester at the Instituto Tecnológico de Estudios Superiores de Monterrey (ITESM), Monterrey, Mexico Campus. In this course, the use of project oriented learning (POL) [3] and collaborative learning [4] are proposed. Then, we describe the design and implementation of a modular, low-cost, three-wheeled autonomous robotic platform, to serve as a base platform from which different applications, educational and research, could be mounted.

Course on Robot Design

Students registered in the electronic systems engineering major at ITESM should take the course on robot design in their last semester. Students from other majors such as mechanical, mechatronics, electronics, and communication engineering are also encouraged to take the course, forming multidisciplinary teams. The main goals the course on robot design pursues are: to teach students about robotic design, get the students as close as possible to solving a real problem, and to show them how to integrate knowledge they gained in subjects taken in previous semesters.

Robotic design is taught by giving the students the hardware and software information they need to design, build, and debug their own robot. Emphasis is placed on mobile robotics because it is a much more challenging field than industrial

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manipulators; in this line, they are given a two-hour introductory, state-of-the-art session on actual research done in the mobile robotics field. Students learn that robotic platforms are systems that can interact with people, each other, and the world around them, using sensors, actuators, communications, and one or more control programs.

On behalf of the second goal, students are encouraged to propose their own ideas on the basis of useful projects, whether for industry, education, home, or entertainment applications. That is, they are motivated to think about proposing solutions to real problems and their social implications, develop the project requirements, evaluate the design parameters of the project, and implement an adequate work plan. However, they are also given the opportunity to work on a more complete platform like the one that will be presented later in this article.

By developing a robotic platform, students have the possibility of applying and integrating knowledge of subjects taken in previous semesters, concretely: microprocessors, sensors and actuators, wireless communications, Internet distributed applications, programming, real-time systems, robot kinematics and dynamic modeling, computer vision, artificial intelligence, digital and analog electronics, circuit design, instrumentation, and control theory.

There are two main conceptual differences of the course taught at ITESM with respect to other courses on robot design. First, students are encouraged to propose their own project; there are no preferred topics. Second, as a consequence of the previous difference, they are not given a common kit. Students are provided only with basic parts (sensors, motors, electronic components, and batteries), although they are encouraged to use recycled material from useless hardware such as old computers, printers, or radio-operated toy cars because we think this helps develop their creativity. Students must design and implement the different boards needed to control a robot (microcontroller-based system and power electronics), i.e., they are not provided with handy boards, dc motor power electronics, or other boards. Other existing courses proceed in a different way. For example, in [5] students are provided with a common kit (LEGO-based) and are encouraged to design a robot for a contest. The course taught in [6] does not require students taking the course to have a specific background, so any student from any discipline, not only engineering related, can take the course on robot design; students are also given a LEGO-based kit as well as all the necessary electronic boards. Similarly, courses given at [7] do not ask for specific background, and it is also oriented to design robots for a contest (using LEGO).

During the course, students work in groups of three or four people in order to get a functioning prototype at the end of the term. Emphasis is placed on obtaining a working prototype, which is necessary to pass the course. From our particular point of view, it is preferable to build up a simple working robot than to specify a very complicated one with lots of functions that is not likely to work in a semester. In this way, students are aware of what it means to develop a real working project in a limited period of time. They realize that, although they have most of the knowledge necessary to build up their project, passing from theory to practice is not so straightforward. Making things work is not that easy. This gives them a first approach to what they surely will find a few weeks after the course finishes, when they get their graduate degree and start working in the industry.

In the first class, the students are asked to bring three or four project proposals with a brief preliminary analysis of the work they imply. It is in this introductory class where a seminar on the state of the art of robot research is given. In the second class, one week later, each team explains and discusses their project proposals with the professor and the rest of the groups. This process enriches the learning of all the students in the class; being exposed to the ideas of the others creates an excellent environment to develop and practice communication and criticism skills.

We have found that the students tend to propose robotics projects that are too ambitious for a semester term (with four months of real available time to work). The role of the professor is very important in this stage to help the students limit the projects so it is feasible to build a working prototype in this period of time. Hence, the main role of the professor here is to advise the teams in the technological feasibility analysis of their projects. After this stage, according to the POL philosophy, the students are encouraged to take responsibility of their own learning. Once the projects for each group are decided in this second session, no more classes are given to the full group of students (except for monthly seminars, as we will explain later). The professor meets each group weekly, helping to solve the students' particular problems they find on their projects and becoming an adviser and moderator for each independent project.

Every four weeks, a class with the entire group of students is scheduled in which each team gives a seminar on the advances of their project to all the students in the class. The presentations include the mechanical design of the robot, the involved electronics, and the developed software/strategy. For the seminar given in the last week of the semester, each team should present a demonstration of the full working prototypes. Also in the last week, they must give the professor a CD containing all the relevant information about the project, mainly, mechanical and electrical designs, developed software, and demonstration videos of the working prototype.

Common difficulties students have with their projects are mechanical design, integration and use of mechanical parts in their robots, use of analog electronics for sensor conditioning, dc or step motor power electronics, and trajectory planning and following strategies. These detected problems help redesign previous courses they have taken by, for example, including more practice on those topics in order to reinforce the learning of those aspects.

The following is a list of some of the proposed projects in the 2004 spring semester course; in Figures 1 and 2, we also show photographs of the two best projects in that course:

- robot arm to classify objects by color using vision
- mobile robot for surveillance using map navigation
- camera-based tracking system for surveillance
- restaurant waiter using mobile robot
- mobile robot to collect tennis balls
- autonomous ship for the tracking of objects on the sea surface
- object tracking with mobile robot
- metallic objects transporter crane.

Modular Robot Platform Design

Students taking the course on robot design are given the opportunity to work with the robot platform presented below. They did not develop the platform; it was developed by the professors in order to use it for the class and show the students a hardware and software architecture that is valid for light industrial applications. By using the platform, different concepts as motion control, trajectory planning, or teleoperation are taught in a practical way to the students. Moreover, students can use the platform to test different hardware modules and software applications they develop for their own projects. At the same time, thanks to the work the students do, more and more applications are available for the generic platform as it is used as a test bed by students. Providing the students with a stable platform where they can test different parts (mainly electronics and software) of their designs has proven to help them a lot in debugging their projects.

General Considerations

The modular, low-cost, three-wheeled autonomous robotic platform design was first conceived for low-duty, common applications in semistructured industrial environments. Such tasks could be, for instance, autonomous transportation, surveillance or inspection in big warehouses, or industrial floor cleaning in different buildings with large floor surfaces, i.e., big malls, airports, or university buildings. However, the modularity and general purpose of this mobile robotic platform makes it very useful in educational and research environments [8]. It can help students in the fields of computer science and electrical and mechanical engineering see the real functioning of what they learn in the classroom [9], which gives a wider view than only focusing on the basic mathematics for autonomous robots [10]. The platform gives the students the opportunity to test different electronics and software design for their projects. The main requirements for this platform were:

- hardware and software modularity: it must be easy to add or remove hardware and software elements and the platform is open
- module independence, in the sense that different design alternatives for the main modules can be tested even though the overall system constitutes a working environment
- maneuverability
- robustness
- safe operation in environments with human presence
- precise motion capability
- high autonomy in energy
- autonomous and teleoperated mission execution.

For industrial applications, the issues of maneuverability, robustness, safe operation, and autonomy are essential to successfully completing a mission. A key issue is the capabilities of obstacle detection and avoidance in order to deal with environments where other mobile robots [11] or humans are cooperating in a production process. To cope with robustness, two modes of operation are designed: autonomous and teleoperation modes [12].

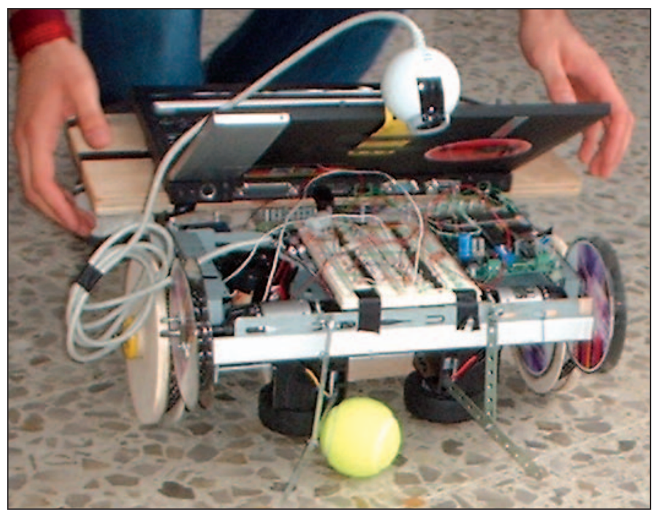

Figure 1. *A mobile robot to collect tennis balls.*

Figure 2. *Metallic objects transporter crane.*

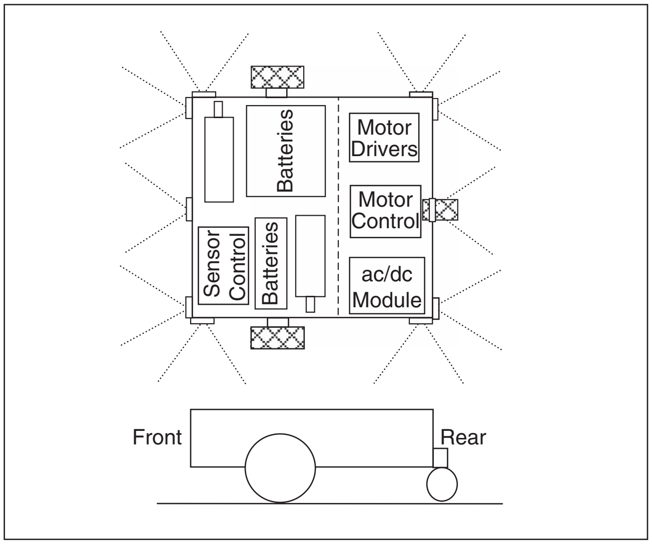

Figure 3. *Basic hardware modules' distribution on the mobile robot.*

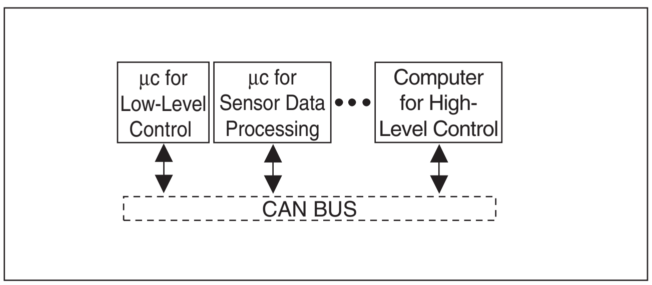

Figure 4. *A distributed hardware architecture.*

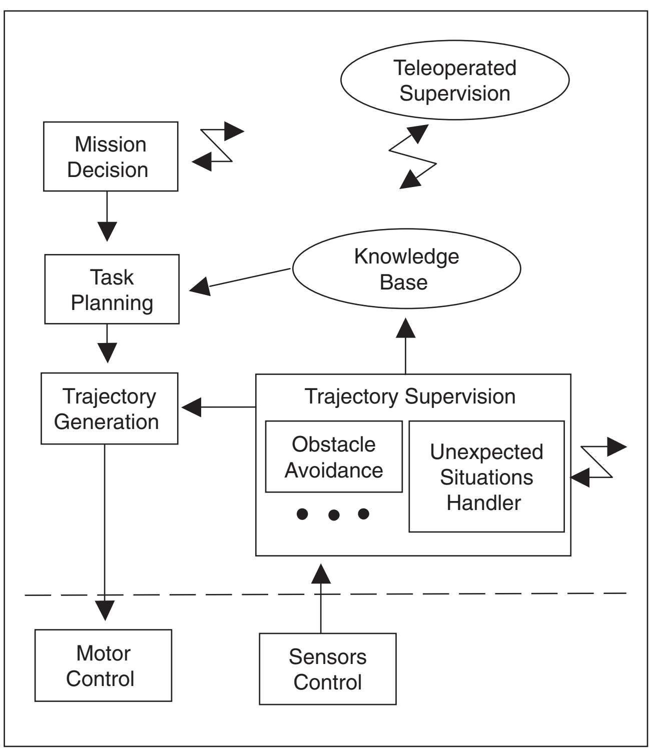

Figure 5. *The general software architecture.*

Hardware Features

The platform has been designed to be square (50 × 50 cm); therefore, its full surface can be used for transportation if needed. A schematic drawing of the mobile platform is given in Figure 3.

In order to address the aforementioned set of general considerations, specific hardware features of the mobile platform are:

- differential driving system based on two independent electric dc motors
- high resolution optical encoders in each motor shaft
- 60–80 kg of payload
- distance sensors
- independent power sources for motors and electronic modules
- distributed control architecture.

The driving and steering system of the robot is composed of a three-wheeled architecture with two independent driving wheels and a passive castor wheel. The steering of the vehicle is done by differential operation of the independent driving wheels, i.e., the vehicle can turn around a rotation axis inside its body. The velocity of the robot ranges from 6 mm/s to 1 m/s. Three 12 V–7 A/h batteries are mounted on the robot. Two are used for powering the motors and the other to power the electronic modules. With the motors at its nominal power, the robot can run up to four hours, giving a high autonomy characteristic.

The control hardware is modular, distributed, and interconnected using a CAN (controller area network) bus, which has been proven to be a robust solution for industrial applications [13]. Figure 4 shows a generic scheme of the hardware architecture.

This architecture allows integrating new modules in a quick and robust form. Moreover, each of the existing modules can be directly substituted by other design alternatives for the same function in order to test different solutions. This has been demonstrated to be very useful in an education/ research area.

Software Modules

As was required for the hardware, the software is also distributed in the different computing elements on the robot, which helps in the development of different applications [14]. Figure 5 gives a general view of the software architecture.

The motor-control software provides the following six primitives

- Mov_motor(axis,dist,Veloc)
- Stop(axis)
- Emergency_stop()
- Reset_dist(axis)
- Read_dist(axis)
- Read_veloc(axis).

The axis parameter stands for the right or the left wheel. The difference between the Stop(axis) and the Emergency_stop() primitives is that while the first performs a deceleration of both motors by progressively lowering the PWM rate, the second one just cuts off the power to the motors. The sensor acquisition data module holds a unique directive: Read_sensors(num_sensors).

With these low-level primitives, the high-level modules do not have to be aware of the kind of hardware that is on the robot, making all the high-level strategies portable to other platforms. The software architecture is semihierarchical. The first thing to do is to decide the mission the robot must accomplish. This can be done either in situ or from a supervisor control post. The mission is then subdivided into tasks, using, if there exists, previous knowledge of the present environment, and then for each task, trajectories are generated in order to successfully complete them. Both tasks and trajectories are supervised by their respective modules (depicted in the same box in Figure 5 for space convenience). While executing a trajectory, different submodules can compete in the robot behavior. Obstacle avoidance, robot life (in terms of battery levels), or an unexpected situation has different priorities in different moments. For instance, when executing a planned trajectory path, if an obstacle is detected, avoiding it (that is, calculating a path to walk around it and then return to the planned trajectory) may have less priority than an unexpected situation or a low-level battery warning. In the last case, the present state of the task and the particular trajectory being performed should be stored and then interrupted in order to go to the nearest refueling point. Once the robot has refilled its batteries (or, if necessary, somebody has changed them) it can go on to the task it was executing.

Students taking the course are encouraged to follow a similar software and hardware architecture, i.e., modular. This helps them be aware that, generally, a system is composed of a set of interconnected subsystems, each having a certain level of independence. It also facilitates the use of the general platform to test their electronic and software designs before being integrated in their own platforms. We have found that students have some trouble in understanding the different behavior competition scheme, but in general, it is solved with practical demonstrations where only two possible behaviors compete at the same time.

Application: Mobile Target Tracker

The presented robot platform was not designed for a specific task but to be a general wheeled autonomous platform from which several applications—educational, research, or industrial—that may need this type of vehicle can be implemented. One application that has been implemented with this platform is following a mobile target in an indoor environment at a fixed distance using the infrared distance sensors at the front of the vehicle (see Figure 3). The mentioned application is simple, but it allows testing all of the robot subsystems and studying its dynamic behavior. A team of students taking the course on robot design programmed it. They used the platform to test their tracking algorithm before putting them in their own platform (in this case, with a different architecture: a vehicle with two drive chains). The target was a little wheeled suitcase pulled by a person (as many people do in an airport every day). This application could be useful,

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for example, to make the robot learn a path to perform a fixed route in order to transport relatively small objects between two points of any industry.

For this particular application, no filtering was foreseen for the case when the sensors are confused with another moving obstacle. The robot is put in front of the object that we want followed (students proposed following a given wheeled suitcase). When the object starts moving, the robot tries to follow it at the specified distance. If, during the tracking, a nonexpected moving object, like a ball, crosses between the robot and the target, the robot may be confused and fail to follow the specified target. In this situation, whether the robot follows its original target or not depends on the velocity of the crossing object: if there is enough time between the robot and the tracked object, the robot will decide to follow the crossing object instead. We have a display of all the infrared sensors available every 64 ms, so this sets up the maximum time an object could be between the robot and the target in order not to confuse the robot. The infrared sensors used compensate for varying light conditions and for different colors of the reflecting object.

The robot performed well except in two situations: when the person pulling the suitcase walked too fast for the robot and when this person changed direction quickly (for instance, suddenly turning 90°). In this experiment, the distance to the target was set to be 50 cm. Figure 6 shows the results of the experiment in terms of distance to the target versus time.

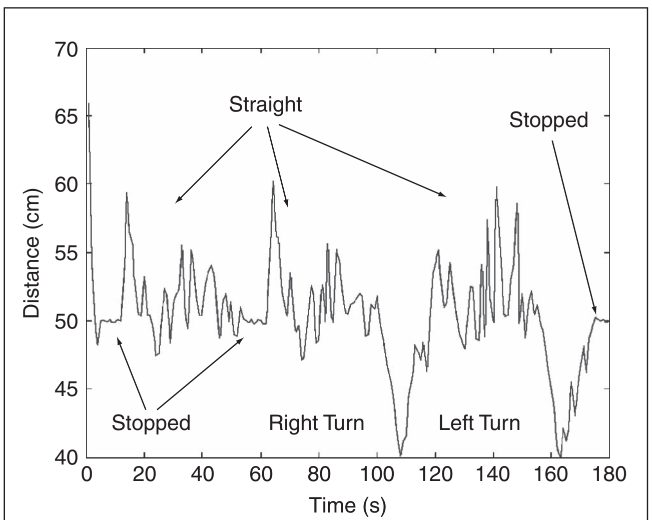

Figure 6. *Distance versus time in a 3-min pursuit run.*

By developing a robotic platform, students have the possibility of applying and integrating knowledge of subjects taken in previous semesters.

A 3-min run was performed with the robot such that:

- the start position was a bit far from the desired distance
- we were stopped at the same position for about 10 s
- we started walking in a straight line for about 40 s
- we stopped again for another 10 s
- we started walking straight ahead again for about 40 s
- we then turned right about 60° in about 15 s
- we went straight ahead again for another 40 s
- we turned left 60° for about 15 s
- we stopped.

At the beginning of the run, the robot is further away from the desired distance, so it is possible to see from Figure 6 that it first adjusts the position related to the target. Then as the target is stopped, the robot maintains accurately the distance to the tracked object; we only find low fluctuations because of different readings from different sensors. Then the target began to move and the robot begins to chase it. As expected, there is a big error in the distance to the target when the movement just starts. Then the target stops and the robot adjusts the required position and maintains it with good precision. Again, the target starts to move and errors in distance are encountered. Note that a similar pattern of error is found in the second straight-line pursuit. Then the target starts turning to the right. When turning, the distance to the target is reduced, and, hence, the error becomes bigger. This has been made because when turning, distances read from each front sensor are different due to the relative instantaneous angle of the target with respect to the front face of the robot. When the turn finishes, a straight line is made again with small error tracking. The randomness of the error is due to the random velocity of a person walking and pulling a suitcase. Finally, a turn to the left is performed, with the same pattern of error as a right turn, and then the run is stopped. Figure 6 shows that the maximum encountered error is about 10 cm, which is 20% of the required distance. For the application that we state here, it is quite a good result if we think that only infrared distance sensors have been used for this issue.

Conclusions

In this article, we first described the "Robots Design" course taught in the last semester at the undergraduate level of the electronics system engineering major of ITESM. In the described course, engineering students learn how to deal with a real problem integrating the knowledge of different subjects they have previously taken, i.e., they are involved on the difficult issue of how to go from theory to practice.

Design courses on robotics are usually based on a standard commercial platform, like LEGO or other educational kits, and the students are given a common task to solve using the kit. However, one of the most important challenges professional engineers must deal with is not only proposing a novel solution for a given problem, but also identifying opportunity areas where they can use their knowledge to develop a new product.

We describe a robot design course based on the didactic technique POL in which the students identify an opportunity area for a robot project application, propose a design, and build a working prototype. The work is done on teams using collaborative learning. Robot design classes under this schema facilitate the students' integration of their knowledge in several areas, producing original and creative robotic applications.

After this experience, we feel that the course could be improved by giving all the students specific seminars on the areas where they shown more trouble, for example: mechanical assembly, control strategies, trajectory planning, or motor drive power electronics. A reasonable scheduling for such seminars would be once every two weeks.

We touched upon the design and implementation of a modular, generic, three-wheeled robotic platform with the following application goals: low-duty industrial applications, platform for research, and educational purposes. One of the major goals was to develop a low-cost platform in order to be affordable for medium- to small-sized educational and research centers, not only to big institutions. Also, this kind of modular platform may be a useful tool to teach and investigate different real aspects of electronic, computer, and control areas.

The presented platform has been used for the course on robot design with two main objectives: as a test bed platform for the students in the course so they can test their designs, mainly electronic boards and software strategies, and to show in a practical way, common problems found in mobile robotics (for example, control strategies, trajectory planning, or obstacle avoidance). A simple student-made application was presented that tracked a mobile target using infrared sensors.

Keywords

University education, robot design, generic robotic platform.

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IROS Fumio Harashima Award

The IEEE/RSJ Conference on Intelligent Robots and Systems has been very successful in contributing to the wealth of the IROS community and in promoting the advancement of intellectual interests in robotics and intelligent systems. The IROS Steering Committee and the cosponsoring societies of IROS have decided to establish the IROS Fumio Harashima Award to express our gratitude to Professor Fumio Harashima for his pioneering research in the area of Power Electronics, Mechatronics and Robotics and his great contributions to the IROS community. The Harashima Award will recognize outstanding contributions of an individual of the IROS community who has pioneered activities in robotics and intelligent systems.

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