Low Cost Robot Design for Research and Educational Purposes

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Abstract. The low price of some robotic platforms is one of the main causes of robotics popularization between all different levels of students. Nevertheless some universities still cannot afford the costs of buying robotic platforms or, due to the lack of interest of the economic councils in certain fields, do not address a sufficient amount of the budget for some fields and courses. Considering presented difficulties, this work describes the design of a robotic platform using only low cost materials that can replace the acquisition of expensive robotic platforms. The results showed that it is possible to build a low cost platform respecting previously described constraints to perform real robotic experiments and validate algorithms.

1. Introduction

Robotics is a research field that attracts the interest of several universities and researchers. The growing interest in the field is a result of the popularization promoted by commercial designers¹ among students of different groups together with the massive dissemination of the research results achieved by universities around the world². Affordable prices of some robotic platforms also contributed however the best platforms are still expensive.

Simulation tools are widely used in robotics, mainly in the first development stages, because it is possible to ascertain the correctness of developed algorithms and perform modifications if necessary without generating excessive costs. However, simulation tools are still not able to represent real situations completely, mostly when the electronic failures have to be considered. Therefore, robotics researchers use simulation to validate the behavior of developed algorithms and real robots to evaluate their real performance.

The problem of robotics field is that even being possible to develop using simulators, real robots are necessary to perform a complete evaluation. Acquiring robots and sensors to perform experiments may not be a problem to some universities but to others is a limiting factor. Robotic platforms³ ⁴ and sensors⁵ ⁶ that are necessary to evaluate

²http://www.journals.elsevier.com/robotics-and-autonomous-systems/recent-articles/
complex algorithms are expensive and not manufactured in a huge number of countries resulting in an import process for acquisition.

This work proposes the design of a robotic platform using low cost materials and electronic waste that can be commonly found in electronic laboratories of universities or can be purchased at low cost all over the world. The result of this work is a robot that has the basic structure to execute a considerable number of algorithms working as an initial research platform and can be easily upgraded with new sensors and actuators.

The remainder of this paper is organized as follows: section 2 describes the theoretical aspects of mobile robotic design, section 3 presents the materials and methods chosen for this work’s robot, section 4 presents the results and analysis followed by the conclusion in section 5 and the bibliography.

2. Design of Mobile Robots

The design of a mobile robot is a complex task that must take into account several issues that will be analyzed below. It’s important to know that mobile robots must cope with many faults being not autonomously fault tolerant in many cases [Crestani and Godary-Dejean 2012] and this fact suggests that the design should allow the robot to deal with problems without being stopped by them. The first step is to identify what environment the robot will work in and what is its main function. The robots can stay indoor or work in outdoor environments that can be structured or non-structured. The environment is a key factor for the design of the robot’s structure. First robots were developed to stay fixed and were just an arm that executed a specific function. These robots did not need a locomotion system or a huge intelligent control because there were no kind of interaction between them and other robots or people. Mobile robots brought with them the concern about the environment and how their structure should be designed to correctly interact with it, allowing robot’s movement. Figure 1(a) presents a parallel between different solutions for locomotion and their behavior considering speed and power. It is important to notice that some choices, such as the walking structures, are more indicated to terrain with multiple gaps than wheeled structures [Siegwart and Nourbakhsh 2004].

Robot’s main function affects other design features. Considering tasks that need a high level of autonomy the batteries should be chosen carefully. Batteries that have high autonomy are usually big and heavy forcing the robot structure to be robust, while low autonomy batteries are small and light. A robust structure in this case can be described as a rigid and resistant basis together with high torque motors necessary to move the robot. This problem is easier to solve if the robot can recharge during the time it is accomplishing a task but this situation is considerably rare in real world scenarios. Other power sources also have problems, for example: (i) robots that use solar energy have to carry more batteries, (ii) robots that use combustion engines are heavier and need a considerably amount of fuel and (iii) other types of power sources can be dangerous or difficult to store and obtain. Figure 1(b) presents different types of power sources and their comparison considering power (Watts/kg) X energy (Watts hr/kg).

3http://www.mobilerobots.com/researchrobots/p3at.aspx
5http://www.phoenixgarage.org/show_article/167
6http://www5.epsondevice.com/en/sensing_system/product/imu/
(a) Comparison between different solutions for robotic motion. The proposed analysis shows that speed should be sacrificed if some hp is needed but the choice is only possible based on environment features [Todd 1985].

(b) Comparison between different power sources for mobile robots [Dowlin 1997].

Figure 1. Robot’s Features Comparison

According to Figure 1(b) the most used type of power sources are batteries. Choose the correct battery to be used in a robotic platform is a difficult task and some features have to be considered: capacity, energy density, voltage, discharge rate, shelf life and temperature dependency. The final project can be compromised if the design analysis skip any of these features.

Other important questions are the shape of the robot platform, how many wheels or legs the robot will have and how these wheels or legs will be fixed to the structure. Robots with legs are usually inspired by nature and have 2, 4, 6 or 8 legs. These legs are usually fixed in the sides of the robot and equally distributed. The problem is to coordinate the movement of each leg correctly in order to perform a fast and secure walk. The size of the legs will depend on the environment and some examples of how to configure the legs can be found in [Siegwart and Nourbakhsh 2004]. Legged robot’s platforms are usually squared or rectangular.

Wheeled robots are the most common type of indoor robots because they are easier and cheaper to build and also easier to program. There are countless different types of wheels and they can be configured of many different ways. The most indicated shape for indoor wheeled robots is the circular shape because it smooths the robot moves and avoid the robot to stuck at corners. Other shapes that have no squared edges are also good choices. If is not possible to build the robot with the described platforms the configuration of the wheels should give the robot a smooth turning.

Mobile robots are programmed also to work in very irregular environments where different solutions are needed. The tracked slip/skid locomotion can solve this problem.
Tracked robots have high maneuverability when working in irregular surfaces compared to conventional wheeled robots but some problems have to be considered: the robot cannot change the orientation without a skidding turn which makes the task a little difficult to be accomplished and the simple turns became a problem because of the difficult to predict robot’s final position due to skidding.

Robot hardware is also very important. Small robots carry small sensors and actuators allowing the designed hardware to be simple. These robots work with low processing power and relatively small amount of memory available. More complex robots usually need a partitioning between the hardware that will control the actuators and the hardware that will control the sensors. This partitioning is necessary because robotic sensors collect large amounts of data that have to be processed in a fast way without interruptions while the actuators also have to be controlled. One possible alternative for the sensors’ control is to embed a notebook in the robot because they are becoming cheaper and their processing power is high and still growing. The problems of the notebook are the high energy consumption and voltage needed, problems that can be well solved by a huge battery (or a considerable number of small batteries) on a robust platform.

Dedicated hardware is more indicated to control the actuators. Some available solutions include microcontrollers\(^7\) and FPGAs\(^8\). Microcontrolled systems are fast and relatively easy to build, program and embed, but the small amount of memory available can become a limiting factor [Iovine 2004]. Microcontrollers operate in slow voltages and the energy consumption is acceptable. FPGAs also have an acceptable energy consumption with the advantage of the development boards being prepared to simplify the control of memory slots. Some problems of adopting hardware with FPGAs are the hardware design time and costs.

This work proposes a robot platform that was designed considering presented design principles but limited to the material that was already available to be reused. Next section describes these materials and some ideas for the different tested designs.

3. Robot Design and Used Materials

Considering that this work’s proposed robot is aimed to be an initial platform for robotics research, it was decided that the structure will be of an indoor robot. This structural decision was taken through a wide analysis of the possible types of robots described in previous section, good commercial designs\(^3\) \(^4\) and interesting previous works [Mundhenka et al. 2003] (that also used low cost components but in a different economic reality).

The design was composed by 2 motorized standard wheels in the front and a free wheel in the back used for a better weight distribution and to make robot’s turns easier. This structure resulted in a basic indoor robot able to allow real execution and evaluation of the developed algorithms. Wheels were fixed in a wooden board and a second wooden board was going to be fixed to the first one using aluminum channels. The higher board carries a notebook and the other one carries the battery and hardware drivers (or a dedicated developed circuit) to control the wheels and some simple sensors.

\(^7\)http://letsmakerobots.com/taxonomy/term/6950
\(^8\)http://www.rtcmagazine.com/articles/view/101763
MDF (lighter) or plywood (robust) squared boards were available and the robot was assembled with both materials and tested. Aluminum channels were chosen to fix the boards because they are light and strong allowing the high to be easily adjusted. Among all possible choices of batteries to power the robot two options were available: one used in no-break devices 12V 24Ah/20h that provides an acceptable autonomy but considerably heavy (317oz) and the second option was a 12V 8Ah battery (105oz) used in alarms and motorcycles.

Robot’s wheels were composed by plastic materials (rigid in the center and softer in the edges). The free wheel was fixed by a screw and the motorized wheels were connected to 12V regular electric motors with reduction by a metal piece that fits in the reduction axis of the motors. Electric motors were fixed to the inferior wooden board by a metal armlet that was easy to build and modify and provided a secure attachment.

The notebook (IBM ThinkPad 600 type 2645 model 21u) was available to be used and had an input tension of 12V enabling a direct connection to a 12V battery. The notebook also had serial and parallel native interfaces. Notebook’s features allows a considerable number of sensors to be easily added to robot’s structure and the hardware to control robot’s actuators to be designed in two different configurations: (i) a small driver could be designed for each DC motor and connected directly to the parallel interface of the notebook that is simple to build and allows the wheels only to move forward or (ii) a microcontrolled circuit could be designed and controlled by serial communication that can contain safety features and different control options. Both options were tested. All electronic components were obtained from other circuits and electronic waste discarded in the lab.

Using all structural and electronic components mentioned above two robot prototypes were assembled and tested. Obtained results and the final configuration of the robot are described in the following section.

4. Results and Analysis

Two functional prototypes were assembled using different materials and hardware configurations. This section describes the assembling process of each prototype, the main
differences between them and the results of the applied tests.

4.1. First Prototype

First robot prototype was assembled using the MDF boards because they were lighter and the impact on the prototype’s final weight was going to be reduced. Aluminum channels were fixed in the boards corners composing robot’s body. It was decided that the notebook was going to be the only processing component receiving all sensors acquired data and controlling actuators drivers from a parallel interface.

Robots actuators were two electric DC motors with input voltage of 12V and a reduction box. Considering energy consumption, the most relevant device in the first prototype was the notebook. The average energy consumption of the notebook was between 1.35A and 1.5A reaching 1.7A when overloaded, whereas the maximum consumption of the two DC motors was 370 mAh. In order to achieve a good autonomy the most powerful battery was chosen (24Ah/20h). Assembled prototype and described components can be visualized in Figure 3.

4.2. Second Prototype

First prototype was tested with a simple ”walk” from a point to another without obstacles. Results showed that MDF material was not solid enough and battery weight caused a bend in the board tilting wheels and interfering with the robot’s movements. Parallel interface also had a small delay to activate the actuators. After analyzing the first prototype and identifying the main problems a new prototype was assembled. The inferior wooden board was changed to a plywood board that was rigid and able to hold either the two battery without sagging. The new board was a little heavier but after fixing the motors the structure sustained itself without damaging the wheel axes. The heavier battery was changed by the lighter one, even with robot’s autonomy decrease, to guarantee that the final structure continued well sustained. The final change was the redesign of the motors drivers and the change of the control interface from a direct parallel communication to a microcontrolled serial dedicated hardware. The design of the hardware was based on ideas
proposed by Wilmshurst [Wilmshurst 2009]. The new robot structure can be visualized in Figure 4 and robot’s hardware diagram is presented by Figure 5.

The new drivers included a H bridge\(^9\) configuration with 2 inputs that can traction wheels forward and backward. A logic protection was also added before H bridges inputs in order to avoid a double command that can cause a short circuit. Dedicated hardware is controlled by a 18F452 PIC\(^{10}\) that can be programmed in C language and has 40 pins that can be used to control more actuators or to receive information of other sensors. A sonar sensor was added to implement a simple obstacle avoidance system.

The robot software is composed by two softwares: one control software executed by the microcontroller and one communication software executed by the notebook. Robot softwares flowcharts are presented by Figure 6. The valid instructions for the robot are forward, backward, turn left, turn right. The first and the second instructions are executed continuously while the other two instructions are executed only for a predefined time (just the necessary time for the robot to execute a turn, previously calculated experimentally). Backward instruction was avoided because there were no sensors to avoid obstacles in this case. To add other sensors the procedure is to connect the sensors to the microcontroller and modify the control software.

Another sensor included was a USB web cam connected to the notebook allowing the implementation of visual navigation algorithms and other sensors can also be connected to the notebook. A new software was developed to communicate the notebook to the microcontroller. The robot was calibrated to receive commands as "$F\ 20$" and walk ahead about 20 centimeters. The turns were programmed to be executed with one wheel traction and also calibrated to receive commands as "$R\ 90$" and turn right about 90 degrees. The obstacle avoidance system was implemented in the microcontroller software and every time the robot found something in an unsafe distance it stops and turns back in curve to a randomly chosen direction (between left and right).

Figure 5. Robot Hardware. 1- PIC 18f452, 2- MAX232 that implemented the serial interface between the notebook and the PIC, 3- Serial interface connection, 4- logic protection to avoid the both side transistors(TIP 127 (top) TIP 122 (bottom)) of the H bridges to be activated at the same time, 5- H bridge for motor 1 control, 6- H bridge for motor 2 control, 7- Ultrasonic sensor. All ground connections were omitted in this diagram but are all connected together to the battery ground. The 5V voltage needed for electronic circuits was obtained from a voltage regulator(7805) connected to the battery.

The platform evaluation considered two different circuits and the results were not as good as expected. The robot was not able to perform a circuit or the object avoidance maneuver perfectly because the wheels were skidding and modifying robot’s trajectory. Second robot was functional and able to execute the basic movements.

4.3. Final Remarks

This work’s robot cost is a interesting information, and to evaluate the final cost of the robot, a commercial robotic platform\(^\text{13}\) that is similar to the proposed prototype, was chosen. The cost of the prototype had to be estimated because most of the used material was available in the lab. So the real cost, the estimated cost and the commercial platform cost were compared as well as their functionalities. All prices were obtained consulting commercial sites and should be considered as a mean.

According to Table 1, the final cost of the second prototype is less than 16% of a similar commercial platform but the commercial platform has better functionalities that

\(^{11}\)http://www.active-robots.com/robots/research-platforms/eddie-robot-platform.html
should be a real need to justify its purchase. Next section presents the conclusions of this work.

5. Conclusion

Robust robotic platforms are becoming cheaper but a considerable number of universities still cannot afford them. This work proposes a robotic platform designed with low cost materials commonly available on universities laboratories. Some problems were detected but the main goal of the project was achieved, to build a robot using low cost materials that could be used to test and validate some algorithms. Based on robot’s structure and available sensors, the robot can execute reactive control algorithms (as tested), visual navigation algorithms, environment exploration algorithms, and any algorithms that a high movement precision is not a key factor.

The great contribution of having a real robot to perform experiments is the fact that the robotics research can go from the simulation stage of correctness verification to the real robot evaluation stage that allows the functional verification of the algorithms.

Results also showed that the materials have to be chosen carefully in order to build robust platforms that can execute algorithms correctly. Other important question is the robot’s autonomy which solution must be a balance between the battery size and the robot’s autonomy needs. Also a well known dilemma should be considered that is the battery size x motor size. A huge motor consumes high amounts of current that only a huge battery can provide. The choice have to find a balance between these sizes. The second prototype presented an acceptable autonomy (about 2 hours fully functional) showing that the battery was a reasonable choice.

Future works can follow many paths. The main modifications in the prototype can include: small wheels with flat tires replacement for larger wheels with rubber tires, dedicated hardware components exchange to new components increasing reliability and design time (that was high due to the incidence of non-functioning components during circuit construction), circular boards should be used instead of squared or rectangular
boards and some sensors should be added to the robot as infra-red, odometers, contact sensors that are also affordable\textsuperscript{12}. Other prototypes can consider smaller robots or larger robots design based on successful experiences\textsuperscript{13} also using low cost materials or sensor development in order to present cheaper alternatives to the available sensors.

**References**


\textsuperscript{12}http://www.trossenrobotics.com/c/arduino-sensors.aspx

\textsuperscript{13}http://www.engineeringforchange.org/news/2012/10/09/challenge_accepted_build_a_robot_for_10.html