A Low Cost Modular Robot Vehicle Design for Research and Education

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Abstract **— In this paper the development of a low cost robotic vehicle for research and education is presented. The vehicle was designed considering minimum cost and maximum capabilities. As a base for testing devices and different type of sensors, a commercially available vehicle was used and modified. Two different version of the prototype vehicle were developed accompanied by the proper software that allows the end user to operate the vehicles as an educational or research platform. The functionality of the vehicles was verified after extensive experimentation.**

I. INTRODUCTION

During the last decade mobile robots of all kinds and sizes, were developed in order to accommodate research and educational needs. Robotics is a multidisciplinary field which includes elements from vehicle/mechanism design, electronics, artificial intelligence, etc. Research wise mobile robots are used to accommodate a wide area of scientific fields and educationally wise their usefulness in the academia is of no doubt. They provide all the necessary means for laboratory exercises in robotics, sensor technology, and basic electric and electronic circuits.

Now days, the evolution of technology achieved a significant reduction in the cost of prototype robotic vehicles that introduce new and more sophisticated capabilities. Commercial robotic vehicles, as well as their components, from all around the world, are available at competitive prices to the contemporary research or academic institutions.

The research and development in the category of mobile robots, during the last decade, resulted in the appearance of many new mobile robots in a wide price range. In [1] a survey of more than 56 up-to-date commercially available robotic vehicles is presented. Based on this survey, some remarks about mobile robots are presented in the following paragraphs.

Roughly 23% of the commercially available mobile robots are able to operate outdoors. This is due to the fact that most of the robots are used in educational and research activities which are conducted in a laboratory environment. This, along with the demand for low cost and relatively simple implementations, makes indoor robotic vehicles much more popular than outdoors.

Low mass is another important issue in the design of robots. That is why the 59% of them weight less than 5kgr and only 27% weight more than 10kgr. As far as it concerns locomotion, the first choice of the vehicle designers is the differential drive as the 54% of them use two drive wheels and one or two castor wheels or points of contact with the ground. The "brain" of the robots is a compact, personal computer unit in the 29% of the vehicles, while at the rest of them embedded microcontroller boards are used.

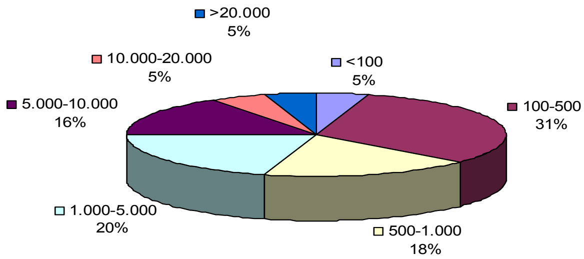

Figure 1. Prices (in €) of the commercially available mobile robots.

The cost of these robotic vehicles as previously mentioned varies. In Fig. 1 the price distribution for the commercially available mobile robots is presented. Almost half of them have a cost lower than 1000€ and although this is an affordable price, the majority of these vehicles share some considerable disadvantages:

- The vehicles construction and assembly is sensitive and their locomotion system is not accurate. Moreover they have certain limitations regarding their motion abilities.
- Their energy autonomy is limited, even for the basic research needs. Their operation time hardly reaches the one half of the hour.
- Their microcontrollers have low computational power and limited memory. They are able to manipulate only simple arithmetic variables and so they can not execute algorithms that use data structures like matrices, for example.
- There is no wireless communication of any kind.
- They have unreliable sensing ability, appropriate only for basic educational applications.

Many of the commercially available mobile robots managed to deal with the previous problems but with a significant cost rise. As a result, the cost of mobile robots that can accommodate both educational and research needs is more than 3000€.

Apart from high costs, these robots usually require dedicated equipment, as usually there is no compatibility with off-the-shelf solutions. Moreover the programming, calibration and customization of the vehicle are not easy tasks and require advanced programming skills together with computer and electronics engineering knowledge.

To our view, a major challenge today is the construction of mobile robots with a better cost-benefit ratio. Today's market offers a wide variety of choices concerning feasible, low cost solutions in almost all parts of mobile robotics technology. The microcontroller technology recently developed ready to use platforms specially designed for robotic applications. Several manufacturers presented powerful microprocessors in compact, low cost electronics boards, equipped with modern operating systems, high level programming languages and compatible with low cost sensing devices. Although their capabilities are inferior of a small PC, their low cost and power consumption as well as their ability to communicate with different types of devices are reasons that make microcontrollers an attractive solution for robotics applications. Further, the achievements in sensor technology reduce the price of suitable for robotic applications sensors. As result, sensors and motors are available in prices quite lower than 100€ and yet reliable enough to use in almost all educational and research robotic applications. Wireless communication is also available in prices lower than 100€ per vehicle via Local Area Network (LAN) or using point to point links. Thus the implementation of educational or research robotic vehicles with a price lower than 1000€ is a feasible project.

This paper refers to a modular robot vehicle design that presents no major theoretical contribution but focuses at the best cost-benefit ratio aiming at a user friendly yet reliable mobile robot, suitable for educational and research applications. Two prototypes are presented that are recently built at the *Intelligent Systems and Robotics Lab* (IS&RL) of the Technical University of Crete.

The rest of the paper is organized as follows. Section 2 presents the main parts of commercial available hardware that was used as testbed towards the hardware design of the prototype vehicles developed. Section 3 presents software modules and vehicle's localization background. In section 4 the experimental area that is used for vehicles verification is described. Finally section 5 presents a brief discussion on the drawbacks of the developed vehicles and some thoughts for further development.

II. Hardware Design

Here the aim of the hardware design is to reduce the cost without minimizing the capabilities of the vehicle. Thus it should use commercially available hardware solutions, with guaranteed compatibility between them. The user should be able to program and interact with the robot without specialized technical training or by being an expert in computer programming. The robot should have modular design which will allow the connection and usage of popular robotic devices without special interfacing [2].

The power system should provide enough energy for 2 hours of full operation. Based on vehicle characteristics (motors, computers on board etc) a rechargeable 7.2V NiMH battery with a capacity of 3000mAh should provide this energy [3]. Another issue is to determine whether the robot will operate indoors or outdoors or even in both environments. This affects the locomotion system and the allocation of the various devices that will be on the chassis.

Based on the above requirements and restrictions, a low budget commercial mobile platform was chosen to be the base for the robot evolution and testing of different devices. The robot chosen was the Rogue Blue robotic vehicle, due to it's low cost and expandability. It hosts the user-friendly OOPic microcontroller which is particularly designed for robotic applications. The OOPic uses an object oriented, high level programming language that is very easy to learn and use. It also maintains a modular design as it is easy to change the devices that are connected to the microcontroller or add new ones using a plug and play philosophy. Rogue Blue chassis has a very compact design, suitable for indoor applications at limited space laboratories. The power requirements of the robot are easily covered by the power supply that was specified in the previous paragraph.

Beside all the previous positive characteristics, the Rogue Blue is a low cost robotic platform that needs certain improvements to accommodate advanced educational and research needs. This is because it is not equipped (at least the basic version) with devices that will allow for complicate experimentation. The first step of the vehicle's upgrade was the addition of extra space in order to accommodate more sensors and devices. After testing, infrared and ultrasonic sensors were chosen as distance measurement sensors. Two odometers, one for each drive wheel, and an electronic compass were also properly fitted on the vehicle. An extra set of batteries was added, so that one set was accommodating the electronic devices and the other set the servos. The final form of the first prototype, which is called HELOT, is presented in Fig. 2.

A drawback of the OOPic microcontroller that the Rogue Blue is equipped, is that it can only implement simple, brief, non-recursive algorithms with minimal memory requirements. This problem was by-passed in HELOT by putting the OOPic to communicate via its serial port with a personal computer in real time, sending and receiving object data, as follows. The microcontroller executes, with high speed, a simple program, which controls and interacts with the objects that correspond to the vehicle's devices. A wireless communication between the PC base station and the serial ports of the vehicles controllers assures high speed, bi-directional data flow. In this way more complicated and computationally demanding operation can be performed. The data flow is implemented with a point to multi-point Bluetooth connection. Moreover, another direct wireless network that enables inter-robot communication and cooperation was installed using a FWCM communication device.

The evolution of the Rogue Blue resulted in the development of more than one alternative edition of modular vehicles, as shown in Fig. 3, which formed the HELOT robotic team. In the middle of Fig. 3 the commercially available vehicle is presented while several variations of it are around it.

Each one of the HELOT vehicles uses a basic platform that consists of the chassis, the microcontroller, the motors and the odometers, various sensor suits and intercommunication devices. After all these improvements the HELOT robotic vehicles, which are variations of the Rogue Blue platform, were proven to be a low cost solution, suitable for non-demanding robotics application.. The cost-benefit ratio of these vehicles permits the low budget laboratories to conduct most of the common educational and research applications.

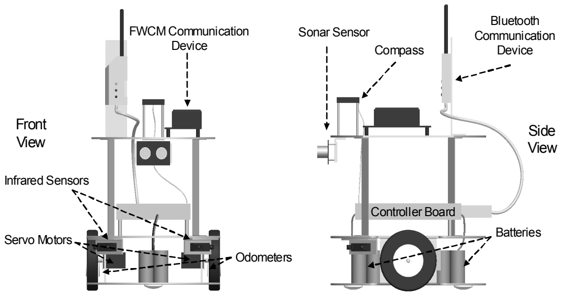

Figure 2. First prototype vehicle based on rogue blue educational robot.

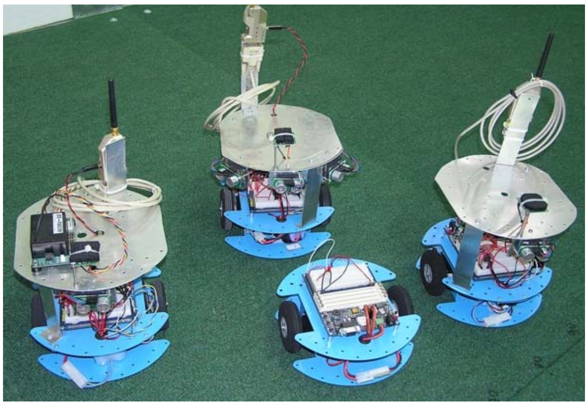

Figure 3. The HELOT robotic team

A. Design and Implementation of a Prototype Robot

Even after improvements and customizations the HELOT vehicles were delicate, without solid construction and thus inappropriate for every day research or educational use. Their locomotion system depended on servos modified for continuous rotation. There were sometimes inaccurate, slow and unreliable.

The prototype robotic vehicle ALE was designed to confront with these drawbacks and still be a low cost, affordable robotic vehicle. ALE is a robust and solid construction with a reliable and accurate differential locomotion system. It hosts two, direct current, gear head motors that are powered by a current driver circuit. There are two, high traction, drive wheels on the back side of the vehicle and one front caster wheel. The maximum width of the vehicle is 30cm, while the contact points of the wheels are 36cm apart. The maximum height of the vehicle is 13.5 cm.

ALE is equipped with the OOPic microcontroller, it has four ultrasonic sensors able to operate in a range from 3" up to 10". It is equipped with two odometers manufactured and an electronic compass. The two DC servos that drive ALE are operating in 12 Volts and can rotate at 120 rpm with a reduction gear 50:1. A wireless Bluetooth communication module allows remote programming and bi-directional data exchange between its microcontroller and a base station or between microcontrollers that lay in different vehicles.

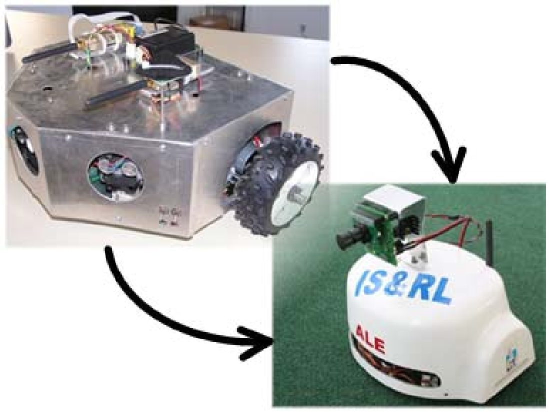

Figure 4. The ALE (top) and the ALE II prototype robotic vehicles

A second prototype design that was based on the experience derived from the ALE project, resulted in the implementation of the ALE II robotic vehicle shown in Fig. 4. ALE II is more compact and has almost the half size and weight of its predecessor. The contact points of the wheels were only 20cm apart. The allocation of devices on ALE II is presented in Fig. 5.

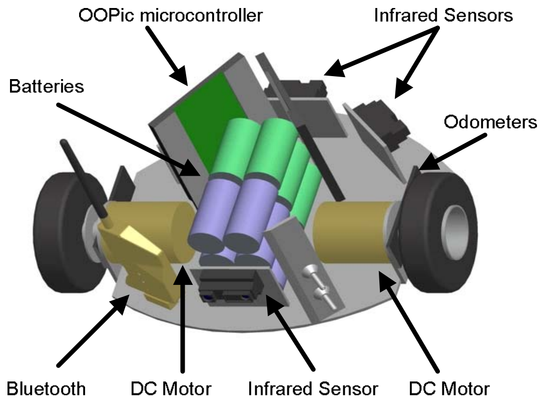

Figure 5. Drawing of the main components of ALE II

The microcontroller that the robot uses is the OOPic. The ultrasonic sensors have been replaced with four infrared sensors since the robot is operating in a small confide space and the infrared sensors were proven to be reliable and accurate in detecting obstacles in the laboratory environment in small distances. Two odometers are responsible for calculating the traveled distance. The DC motors used are operating in 7.2 Volts and they can rotate in 175 rpm, with a reduction gear 50:1. Detailed drawings of ALE II are presented in [1].

ALE II is equipped with the CMU CAM2 digital camera, a device for image processing and pattern recognition, for an additional cost of 150€. There is also Bluetooth wireless communication module for remote programming and bi-directional data flow between the vehicle’s controller and the base station. ALE II offers solution to almost all problem of the previous developed prototypes and yet its equipment costs less than 500€. It was tested for more than six months in a laboratory environment with positive results not only for educational tasks but also for demanding research applications.

III. Software Design

The software design for the HELOT and ALE robotic vehicles follows the same philosophy. The OOPic is running a program which allows the low level control of the devices and data acquisition from the sensors. There is also a wireless RS232 serial link between the robot and the remote computer. Up to seven robots can communicate from a distance of less then 100 meters via this link with the remote computer using a bluetooth device. This bluetooth serial link is adequate for string-type data exchange that requires low bandwidth. This limitation has as a result problems in transferring bigger data structures as the ones used for image and video. This link enables the remote control of the robot as data may flow in real time, to both directions, using the wireless communication. Using this capability it is feasible to run directly on the remote unit navigation strategies compatible with the serial communication that control the vehicle. Many control algorithms demand data structures and computational power that microcontroller is not able to support. Therefore, there is the capability of controlling the HELOT and ALE robots with the aid of a powerful remote personal computer that takes over the complex data structures and the computational load.

This type of system consists of modular hardware and transparent software architectures and allows users to simplify configuring, debugging and refining prototypes [4]. The functions responsible for position detection and sensor processing are running on the remote computer.

All the software running in the remote computer was developed using MATLAB. This choice was made instead of using high level languages due to the fact that MATLAB is ideal for research and educational needs [4], [6]. The time for the implementation of control techniques and navigation strategies is minimized thanks to the variety of the libraries provided. The code can be tested and run without need for further compilation. The communication between MATLAB and the microprocessor on board is made by sending and receiving ASCII messages. The remote computer plays the role of the master and initiates the communication and robot plays the role of the slave and answers only when requested.

The localization of all developed prototypes depends on the sensor readings that are transferred to the remote computer. The position calculation module is based on the equations presented in [5]. ALE II robotic vehicle uses the differential locomotion technique. It has two incremental wheel encoders that are mounted on each wheel counting their revolutions. At a given sampling time interval t the left and right wheel encoders show a pulse increment of N_L and N_R, respectively. The nominal wheel diameter is D_n and the encoder resolution, C_e, is 64 pulses per revolution. The conversion factor that translates the encoder pulses into linear displacement is given by

$$c_m = \frac{\pi \ D_n}{C_e} . \qquad (1)$$

The incremental traveled distance for the left and the right wheel, are $\Delta U_{L,t}$ and $\Delta U_{R,t}$. These are calculated from (2).

$$\Delta U_{L/R,t} = c_m N_{L/R,t} . \qquad (2)$$

The overall incremental linear displacement of the robot's center point C, denoted ΔU_t is

$$\Delta U_t = (\Delta U_R + \Delta U_L)/2 . \qquad (3)$$

The robot's incremental change of orientation is

$$\Delta \theta_t = (\Delta U_R + \Delta U_L)/b , \qquad (4)$$

where, b is the wheelbase of the vehicle. The robot's new relative orientation θ_t can be computed from

$$\theta_t = \theta_{t-1} + \Delta \theta_t , \qquad (5)$$

and the relative position of the center point is

$$x_t = x_{t-1} + \Delta U_t \cos \theta_t , \qquad (6)$$

$$y_t = y_{t-1} + \Delta U_t \sin \theta_t , \qquad (7)$$

Where x_t, y_t are the relative positions of the robot's centerpoint C at instant t.

To support the educational character of ALE robots a custom user interface was developed, a snapshot of which is shown in Fig. 6. The user interface receives and processes all sensor readings and it is used to remotely direct the vehicle. This user interface may be used for undergraduate courses to demonstrate the operation of different sensors, the way a robotic vehicle moves and how it perceives and interacts with its environment.

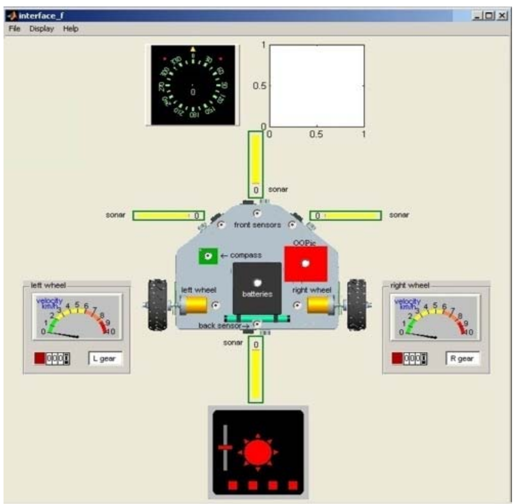

Figure 6. A snapshot of the ALE user interface screen

In the upper part of the Graphical User Interface (GUI) shown in Fig. 6, the compass readings are presented. In the white window, next to compass, the trajectory followed by the vehicle is monitored. The user can monitor the readings of the ultrasonic sensors from the yellow bars, while one can monitor the batteries status. The various devices can be activated or terminated through the GUI. Further a virtual joystick the user can move, turn and adjust the speed of the vehicle.

IV. Robot Validation

A. Experimentation Area

In order to validate the different robotic vehicles which were described in the previous sections an experimentation area was developed, as shown in Fig. 7. It has maximum width of 3.7 meters and maximum length of 4.5 meters. The floor of this area is covered with carpet, in order to minimize the sliding effect. The walls, which were the boundaries, were made from foamy material which allowed the sensors to function properly and also protect the vehicle from crashes during experimentation. The area of experimentation is presented in Fig. 7.

Figure 7. Experimentation area with a single HELOT vehicle moving among static obstacles.

Inside this area the reliability and proper function of all the vehicles are tested. All the vehicles were moving in the same surface, confronting the same obstacles and were surrounded by the same walls. Thus a relative evaluation of the mobile robots behavior and reliability was feasible. Also within this area the robotics researcher or student may calibrate and evaluate different kinds of sensors and navigation methodologies. Many experiments performed to validate the theoretical model of the vehicles kinematics. Laboratory exercises for undergraduate and graduate robotics courses were conducted using this experimentation area in order to test the vehicles under educational conditions.

B. Educational Validation

The last two years the ALE vehicles were used for the laboratory exercises of an undergraduate robotics course at the IS&RL of the Technical University of Crete. These vehicles proved to be reliable during the six hour per day experimentation that was necessary for a period of one month, in order to complete the laboratory exercises. Typical undergraduate exercises consist of obstacle detection and avoidance as well as robot localization and navigation.

The vehicles proved user friendly and thanks to their modularity helped the undergraduate students to quickly learn how to use them and adapt them to the specific needs of each project. The hardware and software design of the vehicle was a helping tool for the students to comprehend and practice all the theoretical background of the robotics course.

The routines for sensor management and localization allowed the students to test different control strategies and experiment in navigation, path planning and learning.

C. Research Validation

As far as it concerns the research validation several research experiments were conducted using the specific robotic vehicles. In [3] a fuzzy logic controller for the control of the HELOT robotic vehicle has been developed. The robot operated continuously for several hours by changing several sets of batteries. The form of the fuzzy logic controller developed is presented in Fig. 8.

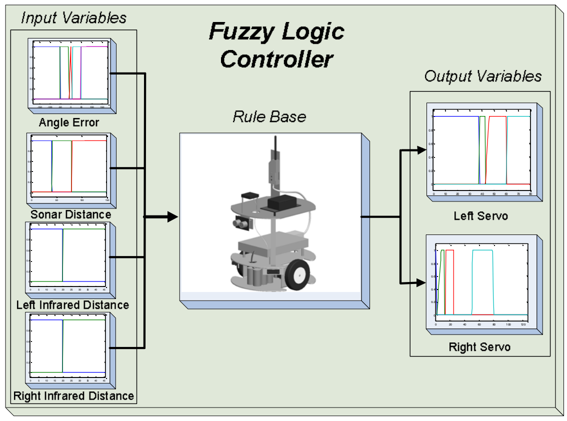

Figure 8. The Fuzzy Logic Controller architecture of the HELOT robot vehicle

The membership functions of the controller developed were evolved using a genetic algorithm with different types of fitness functions. Several behaviors emerged and the vehicle proved a useful tool. The low level data acquisition on board the vehicle was managed by the code running on the OOpic processor while the data were sent and processed in the remote computer using the wireless link. The data exchange rate was approximately 5 readings per second. The fuzzy logic controller and the genetic algorithm were developed in MATLAB and they used the functions developed for data acquisition and robot control.

All the evolution experiments were conducted using only the real robot and not any simulation tool. This time demanding process has the key advantage that incorporates all the factors that are hard to simulate, thus overcoming all the problems which appear due to the use of simulation. A sample trajectory of the robot's path using different type of evolved controllers is presented in Fig. 9.

V. Discussion And Conclusions

In this paper the development of a prototype robotic vehicle for research and education is presented. The low cost of the vehicle without the minimization of its capabilities makes it an appealing solution for the common tasks in a laboratory environment. The use of MATLAB for the control of the vehicle makes it an ideal tool for educational activities since it's easy to use and allows students from diverse scientific fields to develop their routines without the need to be fluent in high level programming languages. On the other hand MATLAB allows the researcher to save time that is usually needed in research, because all the ready made solutions that are provided can be used for the control of the robot. The major drawback of this type of vehicle is the low computational power onboard. This problem can be solved with the installation of a small pc but then the whole design should be reconsidered since the demands in energy and space are going to be a lot higher. Except that the cost of the vehicle will rise significantly.

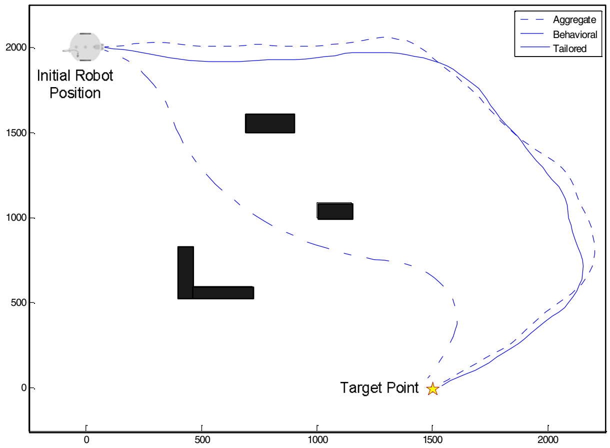

Figure 9. Different trajectories followed by the robot vehicle

Our future work will include the development of a simulation model for the ALE vehicles for the WEBOTS simulation software that will allow us to experiment and reduce the development time of different algorithms.

The standardization of this equipment for laboratory exercises is our long term goal as long as the development of virtual laboratories through the web that will allow students to remotely operate the robots.

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