RESEARCH OF MOBILE ROBOT BEHAVIOR WITH eMIR

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Abstract. In this paper a mobile robot for research and education is described. The main reason for building this robot is the possibility to do research in cognitive robotics, goal oriented robot languages and perception of work environment. Robot is equipped with infrared distance sensors and a camera, and complete environment may also be observed using external camera. Robot kinematics model and speed control are integrated in the robot microcontroller, so user sets robot translational and rotational speed only. Controlling the robot is possible from any programming language and operating system that makes this platform very flexible. Robot is equipped with battery and wireless communication which results in bigger autonomy and connection with more powerful computer. The system is able to do fast check of robot control algorithms for single robot behavior or behavior in group of robots. Three robots have been already built, together with test platform 4 x 2 meter in size.

Introduction

Main topic in robot research today is cognitive robotics, and one of the most interesting applications is in mobile robotics. From robot we expect not only the possibility to move but also dealing with its environment. It is favorable for robot to have human perception of environment and moving inside it, so that communication with human may be as simple as possible, and so making the robot easy accessible to people. Until the end of 90's this goal was first tried to reach using an exact mathematical methods (configuration space, potential fields, equidistant paths etc). This approach had multiple drawbacks so researchers start to use tools like neural networks, fuzzy logic etc. This enabled development of goal oriented languages for robot, in contrast to motion control. As the theory was getting more complex, testing by simulation was not sufficient any more. Therefore many researchers started to build mobile robots with various complexity. In time some expensive models prevailed in research labs (like Pioneer), but also a number of smaller and less expensive models appeared on the market. Soon it was clear that for research in cognitive robotics there is no need for expensive robots [1], but the good ideas and adequate knowledge is what is needed [2]. As this research involves the need for constant change, many researchers found out that it is the best to build their own robots. In these way researchers have full insight in robot behavior, but at the expense of more work involved.

One good example is in [3] in which authors have built a complex mobile robot with multiple controllers and sensors with possibility of the robot control through MATLAB. Authors relay mostly on internal robot sensors (ultrasound and infrared distance meters), but the camera, as a powerful source of information, is missing. In [4] eROSI robot is used equipped with camera, accelerometers and wireless communication. The goal was the guidance on docking station, using only vision system, which is by itself important function to obtain robot independence. Paper [5] describes „wheeled mobile robot" WMR which is in design similar to [3] but oriented towards path following using vision system. Similar system is in [6], describing MiroSot soccer robots. This time vision system is used to control "soccer players" and is located above the playground.

What are common to all those works are relatively simple mobile robot structure and the wish to obtain meaningful robot behavior with a goal to solve relatively abstract jobs.

Basic idea of this research was to build a group of robots capable of dealing with artificial environment. Each robot would have simple task which it needed to execute in an environment not known to it in advance. In the task execution, robot would rely only on its internal sensors, or it would use information from built-in camera. Besides that, for the robot control other camera mounted above work place could be used. Structure of the robot control would be realized using system of independent agents, so that image processing agents would have main role and practically become dominant ones. Robot has a short name eMIR which stands for "educational Mobile Robot Researcher".

Mechanical system

Three identical robots were built, designated with yellow, blue and red color, Fig. 1. Robot motion is realized using so called differential structure. Basic robot dimensions are given in Fig 2. Low robot height of 110 mm and relatively big drive wheels spacing make robot very stable. The actual robot size of 300 x 250 mm is chosen so that typical netbook computer will fit. Robots are built from plexiglass material, lower plate thickness is 10 mm. It enables easy tool handling, so adding new parts is quick and inexpensive. Upper board is made from the same material, 6 mm thickness, so all components between two boards are protected. Wheels are recessed in the robot body therefore no part of robot can stumble into any obstacle. Robot mass is 3,5 kg and is powered by standard 12 V/2 Ah rechargeable battery. This results in 3 to 4 hour autonomy.

Kinematics model of the mobile robot internal and external coordinate velocities is given with following equations:

$$v = D(\omega_R + \omega_L)/4$$
$$\omega = D(\omega_R - \omega_L)/2L \qquad (1)$$

where: v is translational speed and ω rotational speed, ω_R and ω_L are angular speeds of right and left wheel, D = 80 mm is wheel diameter and L = 240 mm is wheel to wheel distance.

Taking into account maximum motor speed, maximum robot speed is around 0,5 m/s and maximum rotational speed is 240 º/s. Drive wheels are covered with rubber to prevent robot slipping.

Fig. 1 eMIR mobile robots

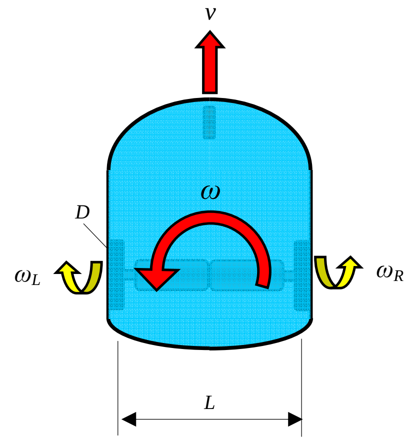

Fig. 2 Robot's basic dimensions and parameters

Energy system

Robot is powered by two DC motors with mechanical gearbox ratio 1:27. Motors type IG-32GM give maximum torque of 0,14 Nm. For motor driving integrated circuit LMD18200 is used (multiwat case) with 3 A current rating. This circuit contains all necessary protection functions, which reduce necessary part count. Motors can work on 24 V but here we use 12 V. This eliminates the need for driver cooling while retaining good driving performance. Maximum output axes rotational speed is 2 s^{-1} while PWM signal frequency is 3,6 kHz. Maximal battery current with all the sensors and camera turned on is 450 mA.

Measurement system

Encoders embedded into motors are used for each wheel speed measurement. Each encoder has two channels with 7 pulse/revolution. Multiplication of encoder pulses and gearbox transfer ratio results in 189 pulse/revolution of gearbox output axe i.e. of the wheel. This gives resolution of 1,9 º per pulse. If the robot movement is only translation then one pulse measures 1,33 mm. Similar math applied on the robot rotation gives result of 556 encoder pulses for 360 º rotation.

Static characteristics of PWM control signal versus free run motor speed is highly linear, Fig. 3. Pulse measurement interval was 260 ms, so that maximum number of pulses is 100. In future projects it is planned to use encoders of somewhat better resolution so that dynamic of speed control will be more favorable.

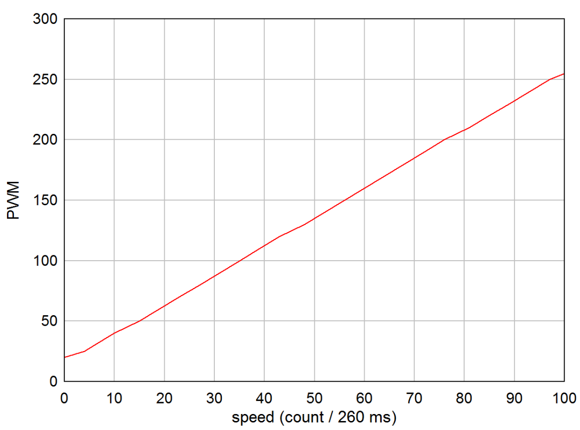

Fig. 3 Static characteristic of DC motor

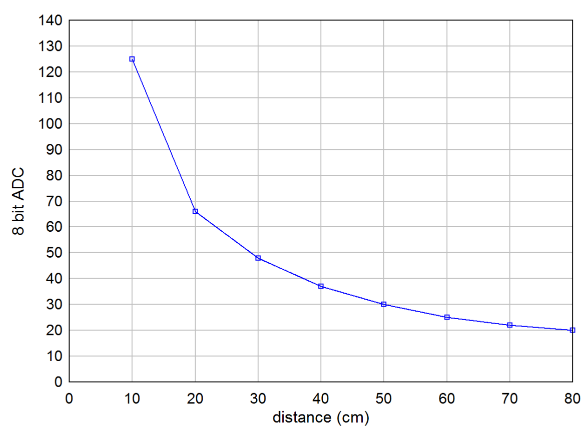

Fig. 4 Characteristic of sensor Sharp GP2Y0A21

During the robot operation battery voltage is measured and used in control algorithm to make decision if the robot should turn off, not to make damage to battery, or alternatively should it go to charging. Charging voltage is also monitored. Robot is equipped with six infrared distance sensors of type GP2Y0A21 with a measuring range 10 to 80 cm. It is well known that those sensors have nonlinear characteristic (Fig. 4) which is internally recalculated to get effective distance in cm. Measuring of each distance channel is done every 10 ms. Measured values pass through the FIR filter after five measurements. Sensor positions on the robot are not equidistant; its placement is shown on Fig. 5. This arrangement of sensors does not give uniform sense of environment, but it is more similar to human perception of the world.

Because distance sensors described do not measure fewer than 10 cm, there are also parallel control distance meters GP2Y0D810Z0F, also produced by Sharp. Their activation means that the obstacle is located between 2 and 10 cm.

Control system

Center of the eMIR robot control system is Atmel microcontroller AT89C51ID2. Having 64 kB of program memory and 1 MHz clock it is quite sufficient for the robot functioning. Functional scheme of the robot control system is given in Fig 6. Wireless communication is carried out by Bluetooth module Sparkfun WRL-00582 having data transfer rate of 57600 bps. As microcontroller does not have A/D converter, external serial converter ADC LTC1294 is used. The robot power supply is controlled with bistable relay, which can be turned off by program, so robot can shut off by itself. In the development phase there is a need for often change of control program, which is also possible through Bluetooth wireless communication. In fact, parallel to main microcontroller there is also auxiliary controller AT89C4051

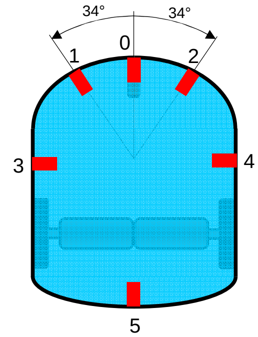

Fig. 5 Placement of infrared distance sensors

for supervision of communication. When it receives certain byte sequence it sets main controller in bootload mode. Eight input/ output lines of the main controller remain free in this version and can be used for additional sensors or LCD display. There is also a possibility for audio signals using the built-in horn.

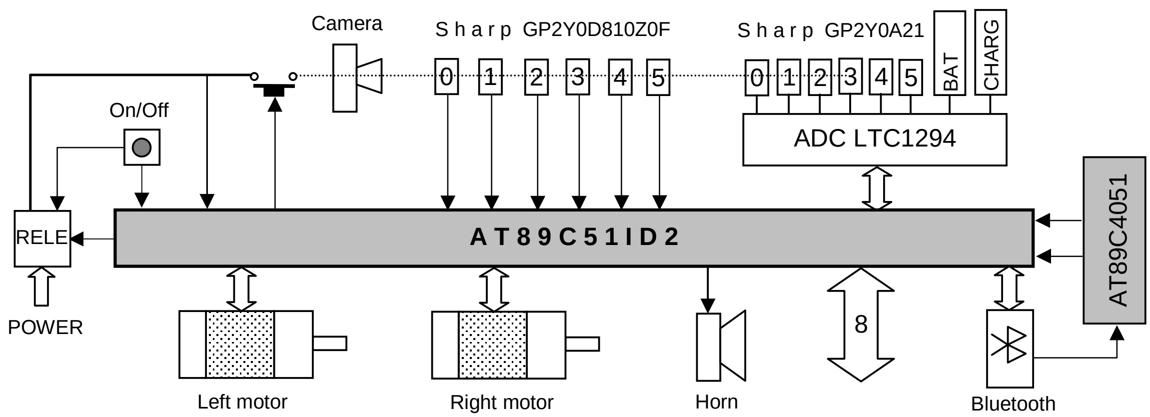

Fig. 6 Functional scheme of control system

The whole control program uses only 3,5 kB of program memory, that is only 5 % of available microcontroller space. Control program provides the following functions:

- supervision of communication and receiving commands
- to control, interpret end execute commands
- to measure motor speed every 260 ms
- to control motor speed every 100 ms using nonlinear PI controller and feedforward
- to read one infrared distance sensor every 10 ms
- to read battery charge state every 100 ms.

The whole robot control algorithm is carried out on personal computer and movement commands are sent to the robot. If the robot is in motion and it does not receive any command during one second, it will stop. If there are no commands in 120 seconds the robot will shut down. Communication between PC and the robot is by data packages in hex system (Table 1) of the following format:
NN aa bb CS /

Table 1. Some eMIR commands

NN	Command	Description
0	`# 00 00 00 00 /`	Stop the robot and exit from a current task.
1	`# 01 vv rr CS /`	Move the robot with translation speed *vv* and rotation speed *rr* (–100 to +100%).
17	`# 11 PP 00 CS /`	Define returned information package PP (0, 1 or 2).
19	`# 13 tt 00 CS /`	Turn on internal horn for time tt tenths of seconds.
255	`# FF 00 00 01 /`	Turn off the robot.

The byte CS describes so called "check sum" and is used as control of package integrity. If NN+aa+bb+CS = 0, command is accepted and executed, if not it is discarded. Data packages from PC to robot are sent 4 to 10 times per second.

If sensors and battery status is requested (PP = 01), this information will be given in the following package:
* 01 aa bb cc dd ee ff gg hh ii CS /
where: 01 – package identifier for the robot sensors
aa – state of digital infrared sensors
bb..gg – measurement of distance sensors in cm
hh – battery voltage
ii – battery charging voltage
CS – control sum.

If the robot kinematics is requested (PP = 02), this information will be given in the following package:
* 02 aa bb CS /
where: 02 – package identifier for the robot kinematics
aa – robot translational velocity v in interval –100 to +100%
bb – robot rotational velocity ω in interval –100 to +100%
CS – control sum.

All data are sent in hex system, and robot status is read 3 to 5 time per second. Video image is transferred independently from the robot control system and any system of video transfer can be used.

Control program on computer may be realized in any programming language, operating system or computer type. All what is important to conform given protocol, communication seed and timing defined.

Example

The goal for the robot is to follow wall from its right side and maintain the distance of 20 cm, using constant speed of 20 %, i.e. around 100 mm/s, while maximum rotational speed is set on 10 % i.e. 24 º/s. When front sensor 0 detects an obstacle on distance 15 cm or less, robot should stop. Right wall has two bends on 45 °. Fig. 7a shows parameters of movement if guidance is realized using only distance sensors 4, while Fig. 7b shows parameters of movement if guidance is realized using distance sensors 2 and 4. Control program is written in Pascal.

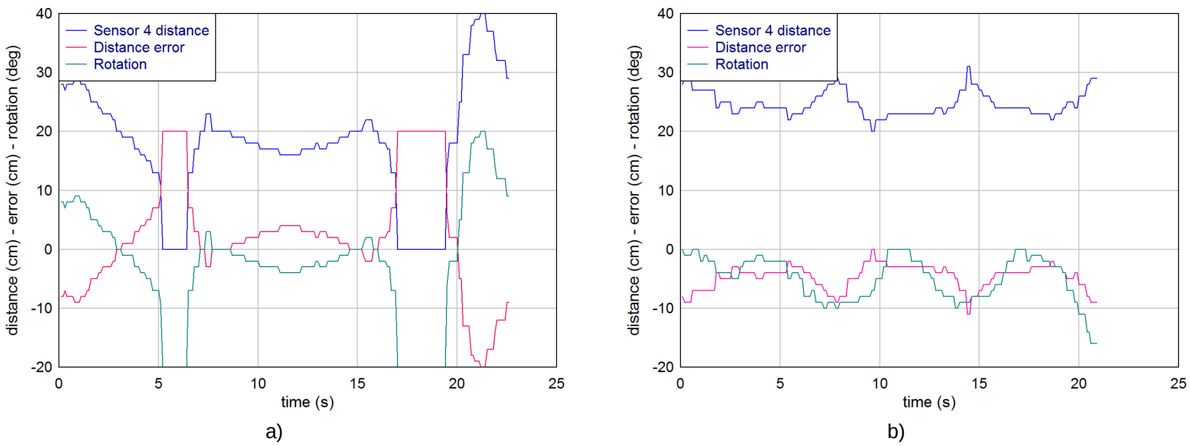

Fig. 7 Wall following: a) by sensor 4, b) by sensors 2 and 4

As it could be expected, guidance using two sensors gives much better result because it can detect distance and needed direction, i.e. it is realized with two state variables. Guidance using one sensor can easily lead to instability.

Conclusion

By realization of the eMIR mobile robots, a good foundation is created for study of mobile robot behavior, single or group. The robots are equipped with internal sensors and camera, so that quantity of information is sufficient for large number of control methods. Because robots can be controlled using any programming language, potential number of users is very large. Additional benefit is external vision system, which is independent from the robot control system.

A preliminary tests show that the robot has very good controllability and reacts fast without oscillation in speed. The robot wheels contact with the surface is so good that there is no slip; therefore commands for the robot relative position and orientation are also possible. Communication over Bluetooth is reliable and works well in real-time.

Further improvement and development will be concentrated in several directions. First, there will be a change in the robot feedback control structure to make the robot start and stop softer. The main development will include the robot guidance by built-in camera which is the main prerequisite for task oriented mobile robot programming language. Parallel with that, task strategies for the robot goal reaching are necessary to be developed. Also, some kind of simple GUI is necessary for testing robot functions and for educational purposes. All of that will be packed in dynamic link library, so it can be used in any programming language.

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