MICRO MOBILE ROBOT FOR TEACHING AND RESEARCHING PURPOSES

D.Dobroczyński, P.Dutkiewicz, T.Jedwabny, K.Kozłowski, J.Majchrzak, G.Niwczyk

Poznań University of Technology, Chair of Control, Robotics and Computer Science
60-965 Poznań, ul. Piotrowo 3A, Poland
e-mail: kk@ar-kari.put.poznan.pl

Abstract. In this paper, construction and software of a mobile micro-robot are presented. Task planning and control techniques for a group of mobile robots are briefly outlined. They co-operate in an unfriendly environment. The robot team has precisely defined task, formulated as a strategy. The vision system delivers data for the trajectory planning program of particular mobile robots. This system is responsible for recognition and computation of position and orientation of all team members, all opponent team members, and of the ball.

Introduction

Micro mobile robot was designed and built under the grant entitled "Task Planning and Real Time Control of s Set of Mobile Robots in an Unknown Environment" sponsored by the State Committee for Scientific Research, Poland (8T11A 02014). A set consists of up to five micro mobile robots, which is called a team. Two teams play soccer [1,3,4] according to the rules similar in nature to the real soccer game. The Federation of International Robot Soccer Association (FIRA) has established these rules. Each team consists of three or five (depending on the category) micro mobile robots, one of which is the goalkeeper. The football field has dimensions of 130×150 cm. Above the field (at the height of approximately 2 m) an industrial camera is mounted. Each robot has specific markers fixed on its top. A vision system is used to recognize two different colors as well as shape of the markers. The vision system tracks the movement of each robot based on the assigned colors and recognizes its position and orientation. An orange golf ball is used as the ball, which is also recognized by the vision system. The host computer has to plan trajectories according to the specified strategy. Commands from the host computer to the robots are sent via radio communication links. Each team has its own dedicated frequency. This is just a sample application, which is very attractive for students and has a strong educational aspect. The robot and ball are depicted in

http://rcin.org.pl

Fig. 1 and the footballfield in Fig. 2. In this work we describe the construction of the micro mobile robot with its on board software and a control software on the host computer.

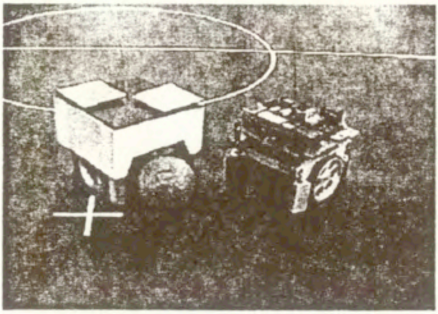

Fig. 1. The micro mobile robot and ball

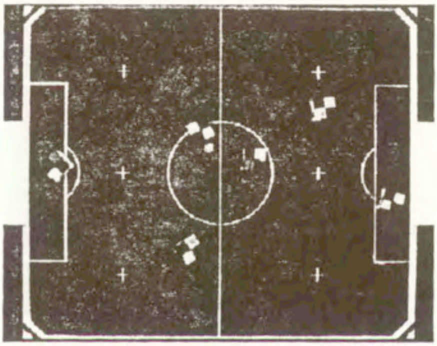

Fig. 2. The football field

1. Description of the robot

The mechanical construction of the micro mobile robot is based on a duraluminium frame, on which two DC motors with gear boxes and a controller board are mounted. Robot has two parallel wheels and in addition is suspended by two slipper elements mounted at the front and back part of the frame. A set of batteries is mounted above the motors in the lower part of the

http://rcin.org.pl

construction. The on-board controller is based on a 33MHz DS87C520 SBC (Single Board Computer) with 16kB EPROM and 1kB SRAM memory. External RAM of 128kB can be used as additional memory to store program or data. In our design 63kB of it is used as a program memory and 63kB as data memory. Alternative way of using it is to assign 2×63kB as data memory. Input/output address memory (to address the external devices) is equal to 1kB. In this address space there are joint axes controllers, 8-bit input and 8-bit output ports. The input port is used to read data from the proximity sensors (up to five) mounted on the robot and to address the individual robots (a 3-bit address). The output port is used to control a number of LED's, which support an external system determining the position and orientation of the robot (a 2-bit address). Control units for the two axes of the robot are LM629 components which work together with the bridge amplifiers L298 with encoders mounted on the gear between motor and wheel (150 pulses/revolution). A general scheme of the robot controller is presented in Fig. 3. Signals from these converters can be used to measure robot position and orientation. Due to a slippery phenomenon between the wheels and the playground encoder measurements not always are correct. Nevertheless they can be used as additional sensors for position and orientation measurements. Two DC motors are controlled by signals of PWM (Pulse Width Modulation) type. Due to the slippery effect and as a consequence accumulation of the position and orientation errors a special blocks which bounds the motor torque has been used. As it was mentioned before a radio communication system through RS232 between the host computer and robot has been used. Since the single board computer DS87C520 has two independent ports an additional module cooperating with the on-board computer via serial port can be used. The power supply of the robot consists of eight 860mAh rechargeable NiMH batteries. The controller is powered by a 5V STEP-DOWN-type PWM pulse power supply with high ampere-hour efficiency.

Below we summarize the basic features of the micro mobile robot:

- dimensions: 7.5×7.5×7.5cm,
- weight with batteries: 0.43kg,
- maximum velocity: 1m/s,
- maximum acceleration: 0.75m/s^2,

http://rcin.org.pl

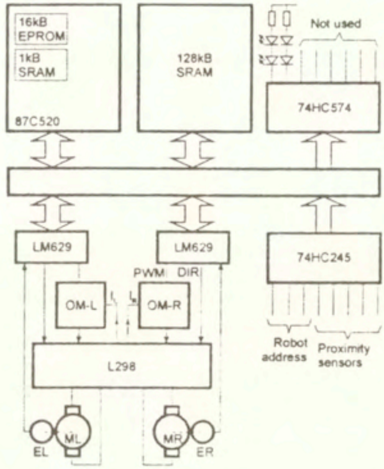

Fig. 3. A general scheme of the robot controller

2.1. On-board programming system

On-board computer is equipped with ROM memory in which a small operating system resides. Actually this system is an interpreter of commands, which allow the robot to calculate its position and orientation based on impulses generated by encoders. One can notice that the SBC used here is a powerful computer and one of the aims in this project is to distribute intelligence between SBC and host computer in order to optimize the programming system, in general. Low level computations allow the host computer to program the desired strategy in more flexible manner. Below we summarize the basic comments, which can be executed by the SBC computer:

- changes velocities of the wheels,
- moves the robot to a desired point with prescribed velocity,
- moves the robot along the arc with prescribed radius,
- allows end trajectory control,
- controls the LED system (when robot is working with an external system which describes its position and orientation),
- reads the position and orientation accumulated by robot,

http://rcin.org.pl

* reads the status word of the robot,
* allows to change a sequence of commends (as an example it allows to send a sequence of commands which has to be executed one by one),
* loads the external memory.

3. A vision system

As it was mentioned in the previous section micro mobile robot can move relatively fast. Encoder measurements are sensitive to the accumulation errors particularly due to slippage conditions between the wheels and playground. This is equivalent to the situation where there is no friction. One has to recall that robots are working in an unstructured environment when the opponent robots move with the same or higher velocities. Therefore it is very difficult to predict the behavior of the robot hit by another one. High accelerations may also cause the same problems. The same situation occurs when robots hit the boundary of the playground and the encoder measurements are not valid any more. This leas us to a conclusion that it is necessary to use an external measuring system. In our case we decided to use a vision which is used to identify different objects on the scene. At the same time the vision system is used to truck the desired trajectory of the robots and their opponent players. A general view of the vision system is depicted in Fig.4.

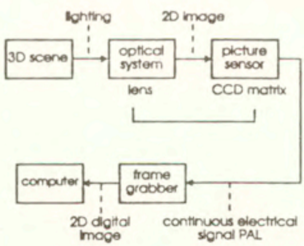

Fig. 4. Hardware structure of the vision system

Industrial camera (in our case color CCD camera manufactured by PANASONIC) is mounted 2m above the playground. Besides that uniform lighting of intensity up to 1000 lux is necessary allow for reasonable camera readings. Lens projects an image on the CCD matrix,

http://rcin.org.pl

which is a converter 1/3" with 450, TV lines. Output signal of the camera works in PAL standard and is an electrical continuous signal with the characteristic features satisfying this standard. This signal is an input signal to the frame grabber (compare Fig.4). In our case it is Korean frame grabber of Media Camp 7 type manufactured by Dooing Electronics. This frame grabber is capable of working with PC compatible computer. The image in digital form can be stored with the following resolutions 640:480, 320:240, 240:180, and 160:120. The maximum working frequency of the frame grabber is 30 frames per second. It allows connecting camera working in either PAL or NTSC system. Data can be stored in either YUV or RGB format (24 bits).

It is obvious that in our particular application the vision system has to recognize both team's robots and the ball. Therefore we have 11 different objects on the scene. Information about the objects is required at real time. This requirement is very stringent. Data acquisition and image processing require a certain amount of time and these are two restrictions, which we have to take into account. Standard PAL allows data acquisition 25 times per second. Currently we are able to process data 20 times per second. This result applies to identification and tracking algorithm of seven objects on the scene (six mobile robots and ball) with probability of error, which is equal to ± one pixel. Recall that the probability of this error means recognition of the required object with its position and orientation with respect to the base coordinate system. Currently we are working on algorithm, which will allow the image processing with speed equal to 25 frames per second. It seems to be an optimal speed for image processing which guarantees real-time performance of the whole system, namely soccer game. This target can be achieved in two ways. Either we use a faster frame grabber with faster access to the digital data or we optimize the procedure for image processing from a numerical point of view. Image processing can be simplified when we analyze only parts of it. Recall that each robot is equipped with a "dress" which consists of two colors. On color recognizes a team and second assigns a team member. Therefore in the simplest case with each team there are four colors associated. The ball according to the FIRA rules is orange. Color recognition is based on analysis corrupted by strong noisy information. During the first tests we observed that nonuniform lighting has a strong influence on the intensity of individual colors as well as it causes that a recognized color changes its clarity. It happens that a source of noise is produced by dresses of the robots. Smooth material causes reflections of the strong lighting. It is

http://rcin.org.pl

assumed (according to the FIRA rules) that lighting should be white. One can use different filters mounted at the optical system but no any improvement was observed.

Talking into account above observations it was decided to define different colors by teaching the vision system. A specially constructed algorithm allows remembering how a particular color looks like in different parts of the playfield in statistical terms. Later on, during a real game the vision system uses this knowledge and allows assigning different points of the image to the desired color. Next recognized points of the image are grouped together to form coherent regions. In order to describe the coherent regions one can use one of the known recursive or sequential algorithm, which groups the regions. These algorithms are known and one can find them for example in [5]. A position of an object is calculated as a mass center x_c, y_c, of the geometrical figure according to the following expressions:

$$x_c = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} jB[i,j]}{S}, \qquad y_c = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} iB[i,j]}{S}, \tag{1}$$

where $B[i,j]$ is an area of the given figure and S denote an area calculated as follows:

$$S = \sum_{i=1}^{n}\sum_{j=1}^{m} B[i,j]. \tag{2}$$

It was experimentally verified that algorithm which is based on Eqs (1) and (2) for figures with uniform color works very well. The micro mobile robots, which play soccer, are dressed up with small uniforms. As a consequence highly noisy signals are present (such as lighting and a way that PAL signals are reconstructed for example) and a proposed algorithm does not give good results. One can ask the following question what is the criterion, which allows classifying indicated area as a seeking object. The proposed criterion tests the color distribution at the surface of the object. Different techniques, which filter out the measurement noise, are computationally too expensive. Therefore one can use the measurement noise as a kind of support in image recognition. The proposed vision system updated with noise distribution measurements allows to identify objects properly with probability around 90%.

Below we summarize on comment, which was very useful in image processing. At the very beginning small differences due to light intensity caused big errors in identification of the

http://rcin.org.pl

objects. By making use of the proposed procedure we observed that changing the light intensity from 1200 Lux to 50 Lux did not have influence as far as the recognition of the objects is concerned. One can conclude that the vision system is capable, based on collected noisy information, to recognize the objects on the scene.

4. Soccer game strategy planning

In this section we discuss some important issues concerning soccer game strategy using micro mobile robots. First we point out some assumptions which are necessary to understand the game. It is assumed that the game is performed on a table (playground) which is divided to M×N rasters. Dimension of the raster is the same as the size of the player. When actual position and orientation of the object is such that the player intersects with the boundaries of the raster then the object occupies more then one raster (one cell of the playground). This simple assumption allows implementing one of the known algorithms, namely APF (Artificial Potential Fields [4]) in order to find a trajectory of the player. As a consequence trajectory can be considered as a sequence of rasters which the player has to follow in order to execute the desired trajectory. Due to the stringent constrains caused by the vision system and dynamically changing environment we take into account only first few elements from the list.

This high level planning resides in the host computer (not at on-board controllers). The trajectory planner has to analyze the actual situation at the playground namely position of own team members and opponent players, as well as, their anticipated direction of movements, position and movement of the ball. Based on this information the planner has to color the actual game field (this part of the playground, which is involved, in the current game). As a consequence rasters are filled out with values. These values decide about the actual artificial potential distribution among the rasters, which are associated with executed trajectory. As an example when the player is approaching the ball the rasters which are associated with opponents will have repulsive values, but the raster associated with the ball will have attractive values. It is one of the simplest ways to color the actual playground associated with a particular part of the game. Now if we want own robots to cooperate than the master occupied by the player should have a small attractive value. One can easily imagine a situation when the player got the ball then the raster associated with it is assumed to be neutral (in case when the player is pushing the ball). At the same time the rasters associated with the goal have

http://rcin.org.pl

attractive values. From this description it is clear that the simplest strategy is of Artificial Potential Fields type which creates at the same time the movement of the robots. Besides that it is assumed that the local minimum (which are typical to the APF method) are not taking into account due to the dynamics of the environment which somehow allow to avoid these cumber some situations. Figure 5 illustrate an example how to color the playground in case of defense and Figure 6 shows the situation in case of attack. In general, a decision process is divided into two steps. In the first step strategy system analyses the whole situation on the playground, namely the system looks for the best decision, which is good for all team members. One can say that all players behave in a similar fashion. These group behavior affect individual players, nevertheless each team member behaves somehow independently depending on its role, which has to play (goalkeeper, defender, forward and helper). Actually only goalkeeper has the role, which is fixed. In contrary to the goalkeeper other players can play a different role according to the dynamically changing situation at the playground. This depends on the team behavior of all players.

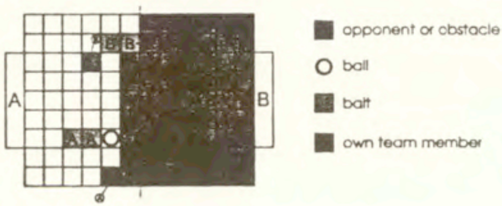

Fig. 5. Coloring the playground for defense

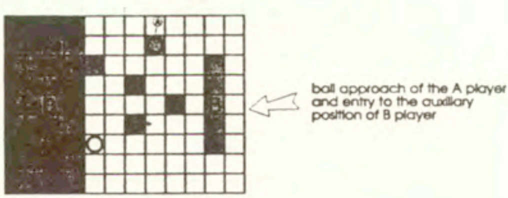

Fig. 6. Coloring the playground for attack

Maps presented in Fig.5 and 6 change dynamically during the game. Therefore each of them has local character and based on it a trajectory path is calculated. The path is calculated from the actual position of the player to the position with the smallest potential. It takes into

http://rcin.org.pl

account all decisions made by the team and at the same time all individual players. A number of points is usually bigger then it is required. Therefore we decided to take into account a smaller number of points in execution of the path. At the same time we filter out a part of the playground in order to reduce the effects of the raster dimension in the nearest vicinity of the player.

In our particular application of the micro mobile robot a goal is to move robots according to desired position and orientation described with respect to the base coordinate frame. In order to achieve this goal two methods were implemented. These methods decompose our problem into two subproblems associated with the execution of the desired task.

The first subtask is to move robot along the arcs with its desired final orientation. The second one moves the robot along straight lines with corrections due to the direction in these instants of time when robot stops momentarily.

The movement along the arcs is calculated based on initial position of the robot and the distance from the desired goal. Taking into account these parameters a radius of the arc is calculated along which the center of the robot is moving. Based on this radius one can calculate a difference between the wheel velocities. When a distance to the goal is far a length of the arc is short but the radius is long. In this particular case robot moves along straight line. In the case when the goal is very close to the center of robot it can backup and turn along axis of rotation, which goes through its center of mass.

The movement along straight line does not require setting up different velocities for the wheels. In order to change the direction of the movement we have to stop the robot and next turn it along the axis passing through the center of mass.

5. Concluding remarks

In this paper a system of cooperating mobile robots was introduced. A multi agent behavior in an unstructured environment is a very difficult task to plan and is a major challenge for control, robotics, and computer science engineers. Another possible application is a military squad behavior, which can also be modeled by a set of micro mobile robots. One can imagine a set of micro mobile robots carrying a common object, which is a difficult problem to be solved.

http://rcin.org.pl
56529
Instytut Podstawowych Problemów Techniki PAN
BIBLIOTEKA

References

[1] JOHNSON, J.H., BOOTH, M.J.: *Robot football: emergent behavior in nonlinear discrete systems*, 1997 Micro-Robot World Cup Soccer Tournament Proceedings, p.87-99, 1997.

[2] LATOMBE, J.-C.: *Robot Motion Planning*, Kluwer Academic Publishers, Norwell, MA, 1991.

[3] SARGENT, R., WITTY, C., BAILEY, B., WRIGHT, A.: *Use of fast vision tracking for cooperating robots in the MIROSOT*, 1996 Micro-Robot World Cup Soccer Tournament Proceedings, p.155-157, 1996.

[4] SHIM,H.-S., JUNG, M.-J., KIM, H.-S., CHOI AND KIM, J.-H.: *Development of Vision-Basic Soccer Robots for Multi-agent Co-operative Systems*, 1997 Micro-Robot World Cup Soccer Tournament Proceedings, p.29-34, 1997.

[5] ZABROCKI, J. ed.: *Computer Graphics*, (in Polish), WNT, 1994.

http://rcin.org.pl