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NAVIGATION ALGORITHM USING FUZZY CONTROL METHOD IN MOBILE ROBOTICS

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The issue of navigation methods is being continuously developed globally. The aim of this article is to test the fuzzy control algorithm for track finding in mobile robotics. The concept of an autonomous mobile robot EN20 has been designed to test its behaviour. The odometry navigation method was used. The benefits of fuzzy control are in the evidence of mobile robot's behaviour. These benefits are obtained when more physical variables on the base of more input variables are controlled at the same time. In our case, there are two input variables – heading angle and distance, and two output variables – the angular velocity of the left and right wheel. The autonomous mobile robot is moving with human logic.

Keywords: fuzzy logic; encoder; membership function; regulation; heading angle; dead reckoning

The issue of navigation methods is being continuously developed globally. One of the great pioneers in the given field is Massachusetts Institute of Technology (MIT) in the USA. For example, Borenstein et al. (1996) designed a model on two driving wheels firmly connected to the drive motors and four auxiliary castors. There is an advantage in a simple solution and high resolution of distance measurement. The gearbox is used for increasing the torque. Probability acceleration skid increases with torque, which are measurement wheels in this case, too. The result is in the heading angle error and position error. The autonomous mobile robot definitely lost the ability to navigate in space.

Robotics algorithm for route planning in the known areas and unknown areas environment is differentiated. Lumelsky and Stepanov (1987) came with a mathematically well-defined algorithm for unknown areas in the eighties. A small device memory was used (the order of tens to hundreds bytes) with using of touch sensors. Navigation was addressed to 2D areas.

Many land navigation techniques are available today. Once the route to take to reach the destination has been decided, it is necessary to ensure staying on that route until arriving. It is possible to choose one of two navigation techniques to do so – dead reckoning or terrain association, whereby one or the other or a combination of both can be used. Dead reckoning is the technique of travelling a set distance along a set azimuth. ('Move 500 meters on an azimuth of 225 degrees.') Dead reckoning has two advantages. First, it is easy to teach and to learn. Second, in most cases it will be the primary method of navigating during hours of limited visibility (Pearson Custom Publishing, 2008).

The aim of this work is to test the fuzzy control algorithm for track finding in mobile robotics. The dead-reckoning technique will be used. Fuzzy logic is based on extending the logical operators to fuzzy sets. The fuzzy sets theory is based on the grades membership element to the set. The value of each element in set is between 0 and 1. This is the basic difference opposite to the classical sets theory. Fuzzy logic provides the language with its own syntax and semantic. The principles of fuzzy control, fuzzification, defuzzification and other fuzzy algorithms are described in Modrlák (2004) and Passino et al. (1998).

Material and methods

The concept of autonomous mobile robot EN20 has been designed to test its behaviour. A differential chassis was used with separate drive wheels and measurement wheels. The block diagram of the autonomous mobile robot is shown in Figure 1. The system contains special modules. Each one is controlled by a single-chip microprocessor. The communication between all the peripherals (MR10, EN10, FR1.0 and BAT1.1) and control module IM10 is based on full-duplex standard SPI.

The bitrate used was 1 Mbps. The communication between IM10 and PC is performed using the wireless standard IEEE 802.15.4 at the bitrate 256 kbps.

The power source was a Li-Ion battery with a capacity of 2.1 Ah and a nominal voltage of 12 V. Information flows between the mobile robot and PC contain information about the battery, current consumption, actual position, encoder states and motors speed.

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Figure 1 Block diagram of the autonomous mobile robot EN20

Table 1 Selected parameters of the sensor TP 6.35 1024 BZ TTL

Maximum frequency	100	kHz
Power supply	$5 \pm 10\%$	V
Current consumption (max.)	85	mA
Maximum rate	100	1/min
Maximum angular acceleration	10000	$1/s^2$
Friction torque	$2.1 \cdot 10^{-3}$	Nm
Mass	36	g
Operating temperature range	-40 to 100	$^{\circ}\text{C}$
Number of pulse per revolution	1024	-

Table 2 Basic parameters of the motors BLY171S-24V-4000 used

Nominal torque in Nm	$63.55 \cdot 10^{-3}$
Nominal voltage in V	24
Nominal power in W	55
Rated speed in 1/min	4000
Torque constant in Nm A ⁻¹	$35.3 \cdot 10^{-3}$
BEMF voltage in V/(1/min)	$3.72 \cdot 10^{-3}$
DC coil resistance in Ω	1.8
Coil inductance in mH	2.1
Moment of inertia of rotor in kg m^2	$6.219 \cdot 10^{-9}$

Figure 2 Membership functions for linguistic variables of distance deflections

We have used the incremental encoders TP 6.35 1024 BZ developed by Megatron, with a resolution of 1024 pulses per revolution. The sensor is based on an optical principle and its mechanical properties are optimal for robotic applications. Namely, they are friction torque, power consumption and resolution. The basic parameters are shown in Table 1. Positions in a special module are calculated for each encoder EN10L and EN10R.

The motor control units MR10L and MR10R are developed for control of brushless DC electric motors (BLDC). Two types of stators are differentiated on the base of back electromagnetic force (BEMF). The first is trapezoidal BEMF, and the second is sine BEMF. Hall sensors are placed in the stator and they provided information about electric rotation angle to the control electronics. Output signals are connected to microprocessor pins directly.

In our case, the BLDC motors BLY171S-24V-4000 developed by Anaheim Automation have been used. The basic parameters are shown in Table 2. Torque characteristics are sufficient for our mobile robot for a 12V supply voltage, too. Motor speed is controlled by eight-bit signed variable, one-bit set direction and seven-bits set speed. Regulation is linearly divided from 0 to 4000 RPM.

Control application was programmed in MS Visual Studio Express C# and Matlab 6.5. Position and heading angle are calculated by the program in Visual Studio. Fuzzy control is provided by the fuzzy toolbox in Matlab. Manual and automatic controls were available.

Results and discussion

Navigation algorithm is determined by setting the fuzzy regulator. There was selected a Mamdani type, with a centroid defuzzification of the fuzzy regulator. We set the linguistic variables at the beginning of fuzzy control design. Linguistic variables were set for distance deflections as follows:

- zero distance, ZD (up to 200 mm);
- near distance, ND (from 200 to 800 mm);
- middle distance, MD (from 500 to 1400 mm);

Figure 3 Membership functions for linguistic variables of heading angle deflections

Figure 4 Detail of the membership functions for linguistic variables of heading angle deflections

Figure 5 Membership functions for the ratio of revolution per minute and rated speed of the motor

- long distance, LD (from 800 to 2000 mm);
- huge distance, HD (down to 2000 mm).

Linguistic variables for heading angle deflection were set as follows:

- huge negative (HN), very large negative (VLN), medium huge negative (MHN);
- large negative (LN), medium large negative (MLN);
- medium negative (MN), small negative (SN), very small negative (VSN), negative low (NL);
- zero (Z);
- huge positive (HP), very large positive (VLP), medium huge positive (MHP);
- large positive (LP), medium large positive (MLP), medium positive (MP), small positive (SP), very small positive (VSP), positive low (PL).

The ranges of heading angle deflection linguistic variables are shown in Figs 4 and 5.

The linguistic variables of the left and right motor were set as follows:

- negative slow (NS), negative middle slow (NMS), negative very slow (NVS);
- very slow (VS), middle slow (MS);
- slow (S);
- middle fast (MF), fast (F);
- very fast (VF), huge fast (HF).

The ranges of linguistic variables of the ratio of motor are graphically described in Figs 6 and 7.

Ninety five conditions were created with the fuzzy toolbox, which is contained in the Matlab application. The RPM regulation works on the base of control surfaces that are graphically described in Figs 8 and 9. Control areas were calculated from all membership functions and all conditions by the Matlab application. The advantage of control is using one function for both motors.

Described control areas were long-term corrected on the base of behavioural tests of the entire system. Basic criterions for correction were a stable motion of the autonomous mobile robot without overshoot and small damping. The variables used were computed by the program in Matlab with using a full duplex wireless connection between the PC and mobile robot. Designed algorithms

Figure 6 Detail of the membership functions for the ratio of revolution per minute and rated speed of the motor

Figure 7 Control area of the fuzzy regulator for the left motor (RRPM – the ratio of revolution per minute and rated speed of the motor)

Figure 8 Control area of the fuzzy regulator for the right motor (RRPM – the ratio of revolution per minute and rated speed of the motor)

contain rotation of the mobile robot around own axis.

The control quality of motor units was evaluated by a track that was created by passed target points by the mobile robot. Target points were selected for all quadrants in order to detect possible errors of designed control algorithms. Targets were positioned on an area of 11.5 m². The number of measurements for one track was ten with seven target points, as shown in Table 3. The average error of actual position measurement was 6.3 mm on the x axis and 29 mm on the y axis. The track was passed in a time of 93 s.

Table 3 Target positions and their sequence

Number of point	Axis x in mm	Axis y in mm
1	2000	0
2	4000	0
3	3000	1000
4	1000	-1000
5	-1000	1000
6	-1000	0
7	0	0

The control of angular velocity of the wheels is shown in Figure 9. The rotation around own axis is controlled perfectly (points 2, 3, 4, 5, 6). Regulation is smooth, without overshoots, which was the aim of the solution.

Conclusion

The application of fuzzy control to autonomous mobile robots was described by Miah et al. (2007). In this case, odometry was used with a gyroscope for correction of errors. The mobile robot was tested in the real-word environment with a velocity of 0.02 m s⁻¹. A Kalman filter was used for filtering measurement. The autonomous mobile robot navigation system with intelligent precision calibration was the result.

In our case, the designed fuzzy control algorithms were tested on the flat surface in the laboratory. Odometry with separated drive wheels and measurement wheels was used as navigation methods. The robot moved for 93 s, and 7 targets were defined in the area of 5 m². With the human logic

Figure 9 Motion of the mobile robot EN20 in the area based on the target points according to Table 3

the autonomous mobile robot moved fully autonomously. The gyroscope and digital filtering were not used in this method.

The benefits of fuzzy control are in the evidence of mobile robot's behaviour. These benefits are obtained when more physical variables on the base of more input variables are controlled at the same time. In our case, there were two input variables – heading angle and distance, and two output variables – the angular velocity of the left and right wheel. Regulation was smooth, without overshoots, which was the aim of the solution.

A possible future research extending this work is in the cooperation of odometry with MEMS inertial navigation sensors.

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