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MOTION CONTROL SYSTEM OF AUTONOMOUS MOBILE ROBOT

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Abstract. *In this article the motion control system of autonomous mobile robot is described. Four motion modes: motion mode "to the target", motion mode "obstacles avoidance", motion mode "along the right wall" and motion mode "along the left wall" are implemented. A method for determining the effective rotation angle of mobile robot which is a linear combination of rotation angles which are obtained in different motion modes and activation coefficients is proposed. Fuzzy-oriented method with high accuracy and performance is used for motion modes implementation and for finding values of activation coefficients.*

Keywords: mobile robot, motion control system, fuzzy logic, linear regression

SYSTEM STEROWANIA RUCHEM AUTONOMICZNEGO ROBOTA MOBILNEGO

Streszczenie*. W artykule opisano system sterowania ruchem autonomicznego robota mobilnego. Zaimplementowano cztery tryby ruchu: „do celu", „unikanie przeszkód", „wzdłuż prawej ściany" oraz „wzdłuż lewej ściany". Zaproponowano metodę do określania efektywnego kąta obrotu robota, która jest liniową kombinacją kąta obrotu, który jest otrzymywany dla różnych trybów ruchu oraz współczynników aktywacji. Do implementacji trybów pracy oraz znalezienia wartości współczynników aktywacji użyto metodę rozmytą o dużej dokładności i wydajności.*

Słowa kluczowe: robot mobilny, system sterowania ruchem, logika rozmyta, regresja liniowa

Introduction

Nowadays autonomous mobile robots can replace human resources at various branches of industry. Mobile robots are used to solve certain household tasks (for example autonomous vacuum cleaners, lawn mowers etc.), to perform tasks in dangerous environments (for example they can be used for space and underwater exploration, including other planets or the world's oceans), for military applications as well as for surveillance, search, security work and so on [5, 6, 8, 13, 16].

Mobile robots can be used at cluttered environments with a lot of obstacles, environments with high uncertainty and dynamically changing environments. Therefore, the vital task is to use the intelligent control system for mobile robots motion control that provides independent tasks execution at an uncertain environment.

There are several approaches for implementation of mobile robot control system [1, 7, 10, 11, 13]:

- Reactive Control. This is an approach that can be used at dynamic, non-structured, unknown environment. Its control signals are based on current sensory information. The main drawback of such approach is the impossibility of mobile robots learning and lack of memory.
- Deliberative Control. This is an approach which is based on sensing, planning and action. In this case, the entire information about the environment is used for decision making about the action. The drawback of such approach is that it can be used basically at static structured environment because of using a lot of time for planning.
- Hybrid Control. This is an approach that combines the reactive and deliberative control systems. But the interaction of deliberative and reactive components needs an intermediary, whose design is typically the greatest challenge of this system. The main drawback is the complexity of adaptation when new tasks of mobile robot motion control arrive.
- Behavior-Based Control. This approach integrates several behaviors of mobile robots that can be implemented simultaneously. Each of behavior can be based on reactive control. So, the combination of them can be used for developing more complex and fast control systems. The main advantage of this approach is the possibility to adapt the robotic system for performing any tasks which are carried out by adding additional modules that implement desired motion modes.

Various methods of artificial intelligence use to implement intelligent control system of mobile robots. Most commonly fuzzy logic, artificial neural networks and neuro-fuzzy systems are used for this purpose. An effective method is the usage of fuzzy logic, because it provides the possibility of mobile robot control even in uncertain complex environment with noisy input data, which can be obtained from sensors. The control system based on fuzzy logic is used for implementing motion control of mobile robot due to its capabilities of inference and approximate reasoning under uncertainty. But the main drawback of usage fuzzy logic for control system of mobile robots is the exponentially increasing the size of rule base with the number of input variables [2-4, 9, 12].

One of the main requirement for mobile robots motion control is the fast response to events, especially when mobile robots operate in a dynamic environment. An effective solution is the usage of behavior-based control which provides a rule base division for several parts and its parallel implementation. Each motion mode of mobile robot is implemented by a part of fuzzy logic rule base.

Different methods of fuzzy logic can be used for motion modes implementation. The most common is the using of fuzzy inference system Mamdani for motion control system of mobile robot. It provides rule base creating with the usage of the human experience. The main drawback of this method is that it ensures a low accuracy due to the output variable dependence of the defuzzification method. The calculation needed to carry out any of defuzzification operations is time-consuming. Rapid response to unforeseen events is critical in the development of mobile robot motion control system. So, it's necessary to use fuzzy-oriented method that provides the necessary accuracy and performance.

1. Development the system of mobile robot control

The main purpose of mobile robot is to achieve the goal at uncertain environment without collision with obstacles. Such motion modes as: "to the target" ,"obstacles avoidance", "along the right wall" and "along the left wall" are implemented for this purpose. The implementation of each motion mode is carried out using a method based on fuzzy logic.

The input data received from sensors and machine vision system. The input linguistic variables for motion mode obstacles avoidance, motion mode along the right wall and motion mode along the left wall are the distance to obstacles at front side, right side and left side of mobile robot. The input linguistic variable for motion mode to the target is an angle that calculates as difference between the direction to mobile robot motion and the direction to the target. The output linguistic variable of each motion mode is a rotation angle of mobile robot. The value of output data influences for forming control signals which comes to actuator of mobile robot. Depending on the type of mobile robot the following control signals as linear and angular velocity or rotation angle of wheels can be used.

The rotation angles which are obtained in different motion modes are used to determine the effective rotation angle of mobile robot. We propose to use a method for determining the effective rotation angle of mobile robot which is a linear combination of rotation angles which are obtained in different motion modes and activation coefficients, which represent the degree of activation for each motion mode as follows:

$$\theta = T_1 q_1 + T_2 q_2 + T_3 q_3 + T_4 q_4 \qquad (1)$$

where T_1, T_2, T_3, T_4 are the activation coefficients of each motion mode, q_1, q_2, q_3, q_4 are rotation angles which are obtained at different motion modes.

The same input linguistic variables are used for determining the activation coefficients. That is, the input linguistic variables are the distance to the obstacles and an angle that calculates as difference between the direction to mobile robot motion and the direction to the target. The output linguistic variable is the value of the activation coefficients, which ranges from 0 to 1. Membership functions are identical for all activation coefficients which determine the degree of activation for motion modes. Triangular membership functions are selected as they are easy to implement.

There are three linguistic terms for input linguistic variables that represent the distances to the obstacles. They determine a small, middle and large distance to the obstacles at the right of mobile robot, at the front and at the left. The input linguistic variable which represents an angle that calculates as difference between the direction to mobile robot motion and the direction to the target is described by linguistic terms which perform location of a target according to mobile robot: at the right («Negative»), straight ahead («Zero») and at the left («Positive»). Output linguistic variable of each motion modes which determines the rotation angle of mobile robot is described by linguistic terms which perform turning to the right, moving straight and turning to the left respectively. Output linguistic variable which represents the value of activation coefficients for each of motion modes contains five linguistic terms.

Fuzzy-oriented method, which provides the necessary accuracy and performance should be used for finding the output values of motion modes and activation coefficients. We propose to use a method where the stages of accumulation and defuzzification are replaced by multiple linear regression model. It would reduce the computational complexity and improve the efficiency of motion control of mobile robot. Three terms of output linguistic variable are used to calculate the rotation angle of each motion mode so the linear regression equation is determined as follows:

$$q_i = a_0 + a_1 Fy_1 + a_2 Fy_2 + a_3 Fy_3 \qquad (2)$$

where a_0, a_1, a_2, a_3 are coefficients of linear regression model, $Fy_1 ... Fy_3$ are values, which are obtained after passing stages of fuzzification, aggregation and activation; q_i is a value of the rotation angle of some motion mode of mobile robot $i = \overline{1,4}$.

Five terms of output linguistic variable are used to calculate the value of activation coefficients so the linear regression equation is determined as follows:

$$T_i = b_0 + b_1 Ft_1 + b_2 Ft_2 + b_3 Ft_3 + b_4 Ft_4 + b_5 Ft_5 \qquad (3)$$

where $b_0, b_1, b_2, b_3, b_4, b_5$ are coefficient of linear regression; $Ft_1, Ft_2, Ft_3, Ft_4, Ft_5$ are values, which are obtained after passing stages of fuzzification, aggregation and activation; T_i is a value of activation coefficient $i = \overline{1,4}$.

Fuzzy-neural T-controller is used to determine the coefficients of linear regression. It is based on fuzzy geometrical transformation model. The main advantage of this model is a providing of a high precision of operation in comparison with any known algorithms of FIS. A software TController Workshop is used for implementation T- controller [14, 15].

Values that represent the entire domain of definition of the linguistic variable are used as input data for T-controller. We use 567 values as the size of the database to simulate such motion modes as: "obstacle avoidance", "along the right wall" and "along the left wall". We use 19 values as the size of the database to simulate motion mode "to the target". We use 3969 values as the size of the database to simulate the finding of activation coefficients. All data from the databases are fed to the input of T-controller, where they are used for finding crisp values of output linguistic variables such as rotation angles and activation coefficients. The same data are used for finding values $Fy_1 ... Fy_3$ and $Ft_1 ... Ft_5$. The method of least squares is proposed for calculating the linear regression model coefficients.

After finding coefficients of linear regression model the equation (2) for developed rule base is determined as follows:

- For motion mode "along the right wall":

$$q_1 = (-0{,}00495) + (-89{,}9942)Fy_1 + \\ + 0{,}01008 Fy_2 + 89{,}99874 Fy_3 \qquad (4)$$

- For motion mode "along the left wall":

$$q_2 = 0{,}00495 + (-89{,}9987)Fy_1 + \\ + (-0{,}01008)Fy_2 + 89{,}99424 Fy_3 \qquad (5)$$

- For motion mode "obstacle avoidance":

$$q_3 = 6{,}43806 + (-14{,}05017)Fy_1 + \\ + (-8{,}55846)Fy_2 + 21{,}73932 Fy_3 \qquad (6)$$

- For motion mode "to the target":

$$q_4 = (-90{,}01872)Fy_1 + 1{,}70478 \times 10^{-9} Fy_2 + \\ + 90{,}01872 Fy_3 \qquad (7)$$

After finding coefficients of linear regression model the equation (3) for developed rule base is determined as follows:

- For motion mode "along the right wall":

$$T_1 = 0{,}0693 + (-0{,}069293)Ft_1 + (0{,}234891)Ft_2 + \\ + 0{,}875218 Ft_3 + 0{,}36326 Ft_4 + 1{,}018323 Ft_5 \qquad (8)$$

- For motion mode "along the left wall":

$$T_2 = 0{,}069298 + (-0{,}06929)Ft_1 + (0{,}234895)Ft_2 + \\ + 0{,}875195 Ft_3 + 0{,}363257 Ft_4 + 1{,}018326 Ft_5 \qquad (9)$$

- For motion mode "obstacle avoidance":

$$T_3 = 0{,}069273 + (-0{,}06919)Ft_1 + (0{,}234971)Ft_2 + \\ + 0{,}875266 Ft_3 + 0{,}36325 Ft_4 + 1{,}018607 Ft_5 \qquad (10)$$

- For motion mode "to the target":

$$T_4 = 0{,}069361 + (-0{,}069367)Ft_1 + (0{,}234868)Ft_2 + \\ + 0{,}875175 Ft_3 + 0{,}363215 Ft_4 + 1{,}018219 Ft_5 \qquad (11)$$

During the motion control of mobile robot, input data which are obtained from sensors and machine vision system passes stages of fuzzification, aggregation and activation. These obtained values are substituted into the equation of linear regression (4-11) and the desired output value is obtained.

2. Simulation of the system for mobile robot motion control

We propose to compare the proposed fuzzy-oriented method of mobile robot motion control with one of the most common FIS Mamdani. The comparison was carried out under identical conditions using the same values of membership functions and fuzzy logic rule base. The simulation is performed in C # at the software Visual Studio 2010.

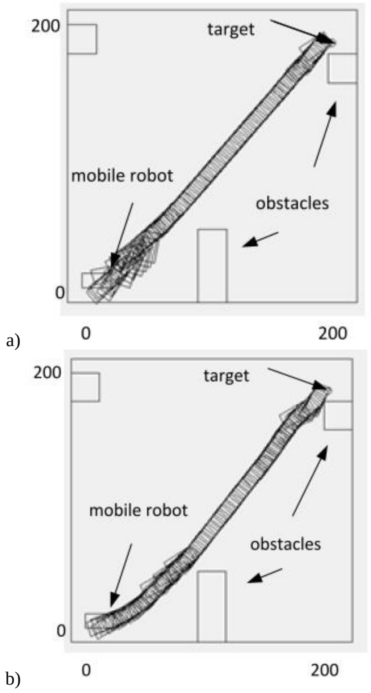

Fig. 1. X-Ypath of mobile robot: a) with the usage of Mamdani FIS; b) with the usage of developed fuzzy–oriented method for motion modes implementation

Let us consider the motion of mobile robot to the target. Fig. 1 shows the X-Y path of mobile robot. Initial conditions: the center of mobile robot is located at coordinates (X = 30; Y = 15), the target is located at: (X = 180; Y = 180).

The goal is reached with the using of proposed method and FIS Mamdani (Fig. 1). But it is clear that the frequent changes of the rotation angle of mobile robot is carried out with the usage of Mamdani FIS at the beginning of moving. The centroid method for defuzzification which is used at Mamdani FIS depends on the shape of the membership function of the output. Different rotation angles are obtained at different motion modes during mobile robot motion. A negative value of rotation angles indicates turning mobile robot to the right, positive value of rotation angles indicates turning mobile robot to the left. Fig. 2 shows the values of rotation angles for motion mode "along the right wall" using the proposed method and Mamdani FIS.

The value of the rotation angle (Fig. 2a, c) without activating coefficients is reduced to a maximum value when there are no obstacles at the right of mobile robot. When there are no obstacles at the right of mobile robot, the activation coefficient is close to zero. So the rotation angle of mobile robot with activation coefficient is close to zero too in this case. There were two obstacles at the right of mobile robot during its movement so the value of rotation angle is slightly varies at the beginning and at the end of route with the usage of proposed method and Mamdani FIS. At Fig. 3 you can see output values for motion mode "along the left wall".

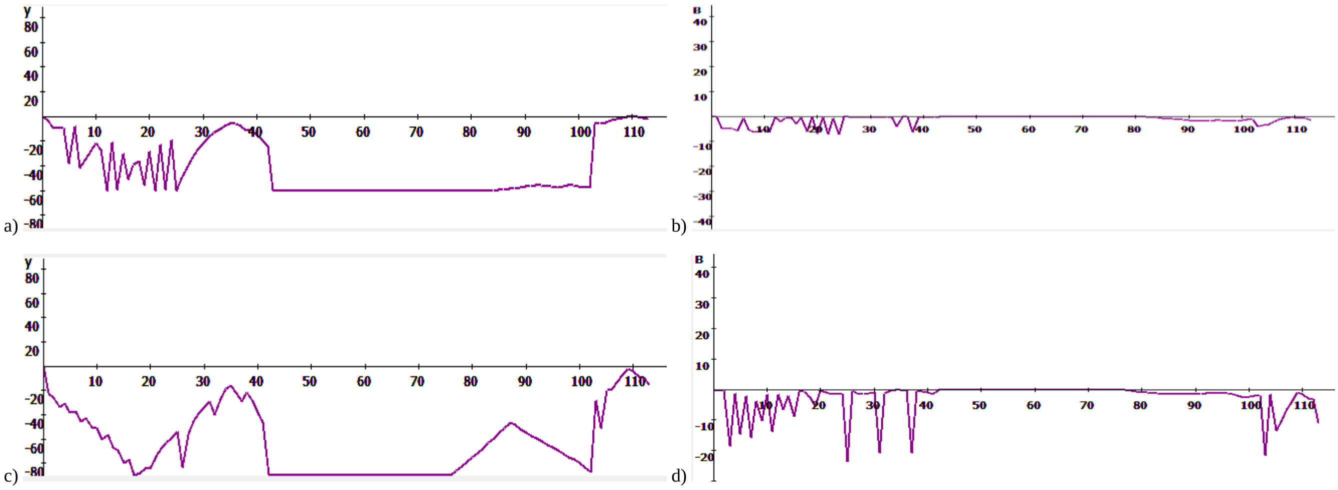

Fig. 2. Output values for motion mode "along the right wall": the rotation angle without activating coefficient using the Mamdani FIS (a); the rotation angle without activating coefficient using the proposed fuzzy-oriented method (c), the rotation angle with activation coefficient using the Mamdani (b), the rotation angle with activation coefficient using the proposed method (d)

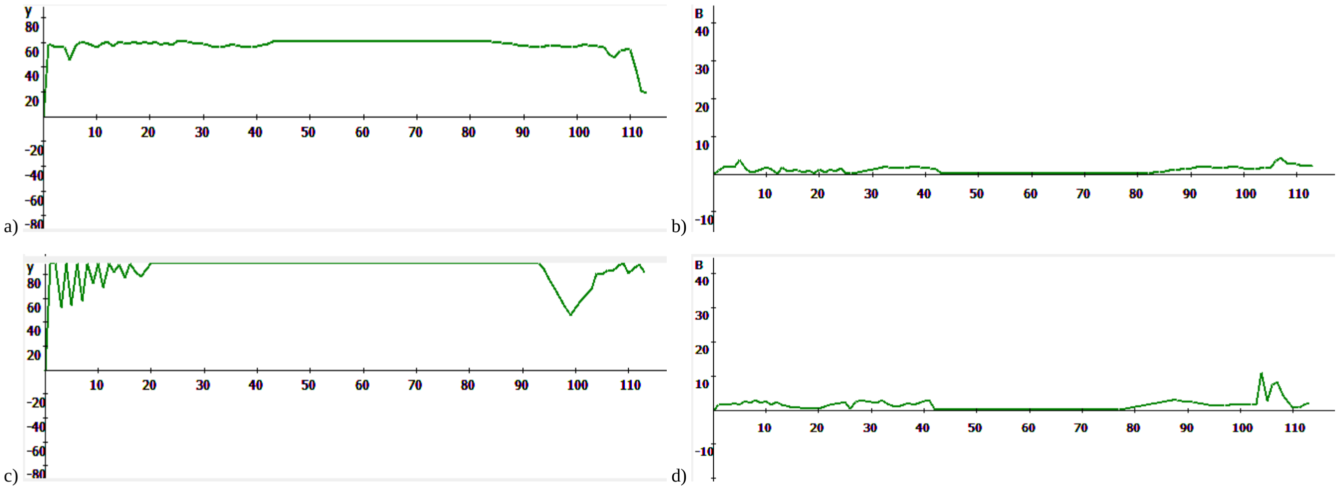

Fig. 3. Output values for motion mode "along the left wall": the rotation angles without activating coefficient using the Mamdani FIS (a), the rotation angles without activating coefficient using the proposed fuzzy-oriented method (c) the rotation angle with activation coefficient using the Mamdani (b), the rotation angle with activation coefficient using the proposed method (d)

Obstacles at the left are absent almost the entire path of mobile robot. So, the value of rotation angle without activating coefficients (Fig. 3a, c) increases to the maximum value (about 60 degrees for Mamdani FIS and about 90 degrees for the developed method) which indicates movement to the left. The activation coefficient is close to zero and therefore the resulting rotation angle is close to zero too. At the end of the path a wall at the left of mobile robot can be considered as obstacle. At Fig. 4 you can see output values for motion mode "obstacle avoidance".

Obstacles at the front of mobile robot are absent almost during the entire path except the end when goal is near wall. So, the value of rotation angle without activating coefficients (Fig. 4a, c) are closed to zero and became increasing only at the end of route. Therefore the resulting rotation angle of this motion mode (Fig. 4b, d) is close to zero almost during the entire path of mobile robot. At Fig. 5 you can see output values for motion mode "to the target".

The oscillation of rotation angle of mobile robot occurs at the beginning of the movement at Mamdani FIS (Fig. 5a). So, it remains at the rotation angle with activation coefficient (Fig. 5b). With the usage of developed method the mobile robot moves to the target with minor adjustments (Fig. 5c, d).

Fig. 6 shows the resulting values of mobile robot rotation angles, values of distance to the target by using the proposed method and by using Mamdani FIS.

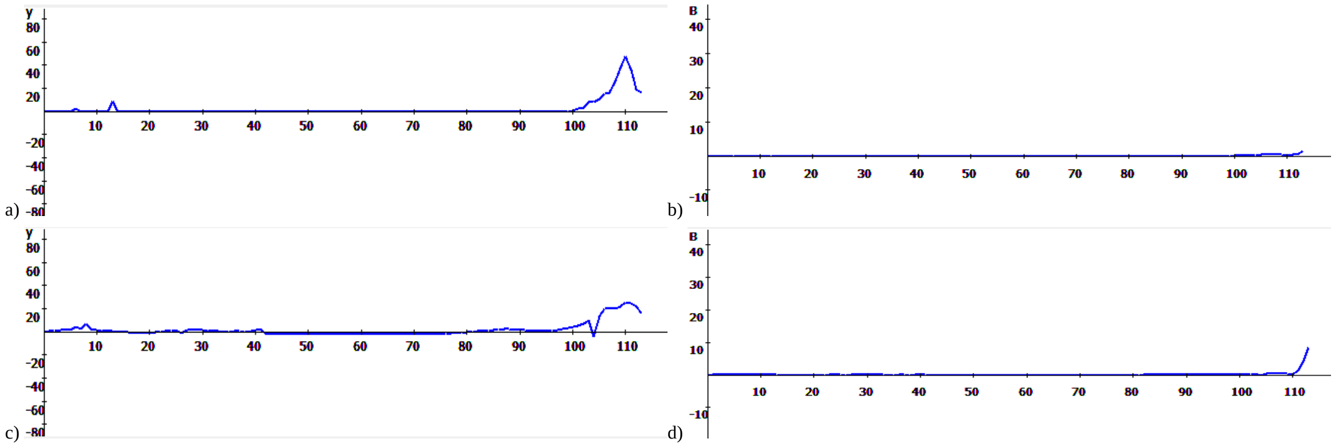

Fig. 4. Output values for motion mode "obstacle avoidance": the rotation angles without activating coefficient using the Mamdani FIS (a) the rotation angles without activating coefficient using the proposed fuzzy-oriented method (c), the rotation angle with activation coefficient using the Mamdani (b), the rotation angle with activation coefficient using the proposed method (d)

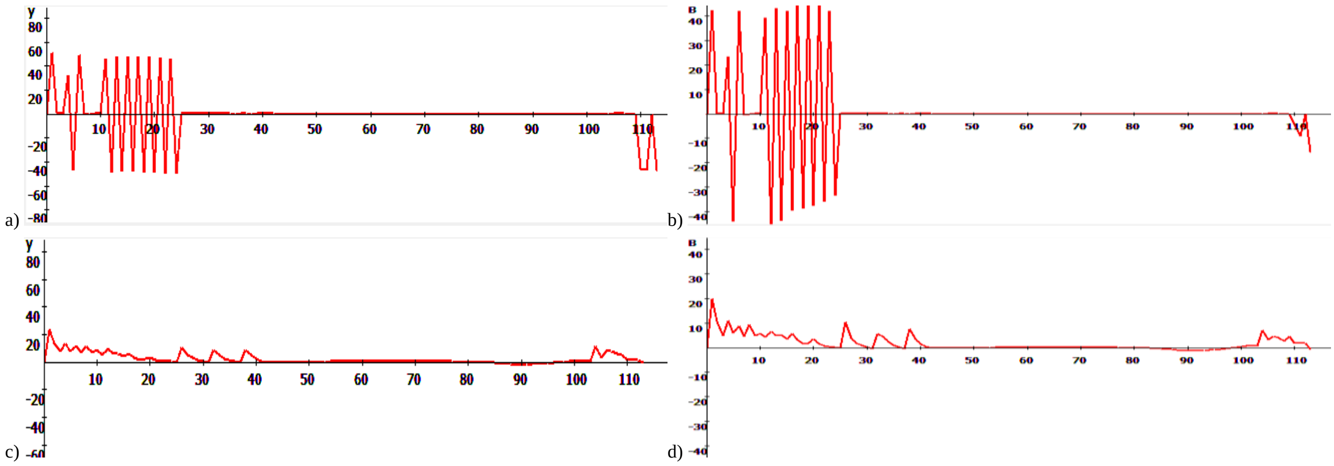

Fig. 5. Output values for motion mode "to the target": the rotation angles without activating coefficient using the Mamdani FIS (a) the rotation angles without activating coefficient using the proposed fuzzy-oriented method (c), the rotation angle with activation coefficient using the Mamdani (b), the rotation angle with activation coefficient using the proposed method (d)

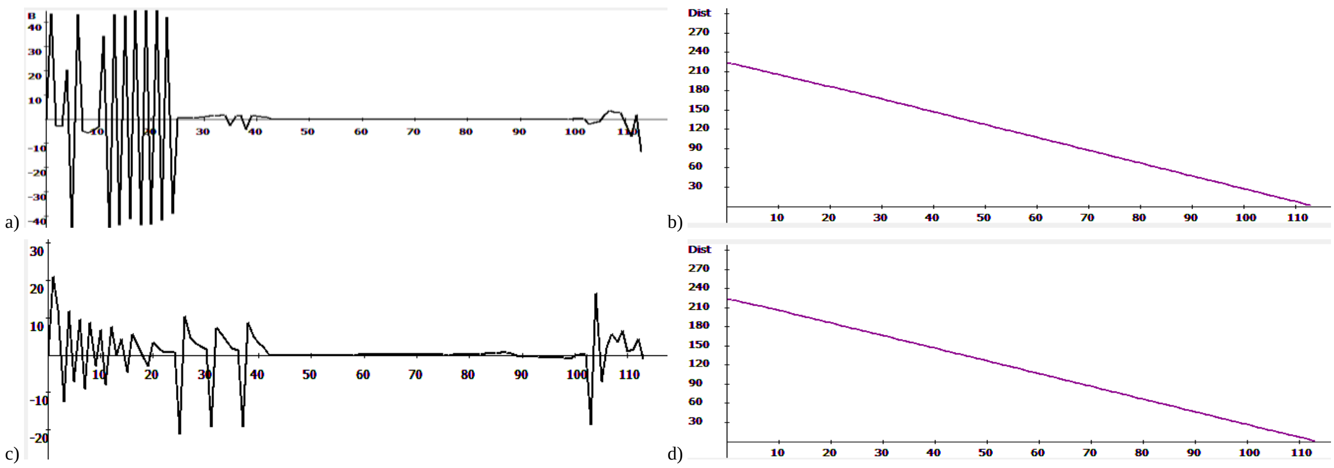

Fig. 6. Resulting values of rotation angle of mobile robot using Mamdani FIS (a), resulting values of rotation angle of mobile robot using proposed method (c), distance to the target by using Mamdani FIS (b) distance to the target by using proposed method (d)

Fig. 6a shows the resulting rotation angle of mobile robot using the Mamdani FIS and it is significantly oscillated at the beginning of the movement. The resulting value of the rotation angle of mobile robot using the proposed method (Fig. 6c) changes at the beginning of the mobile robot movement, but this deviation are not so large and ended when mobile robot pass obstacles. Values of distance to the target (Fig. 6b, d) have almost the same and decreasing with using Mamdani FIS and proposed method.

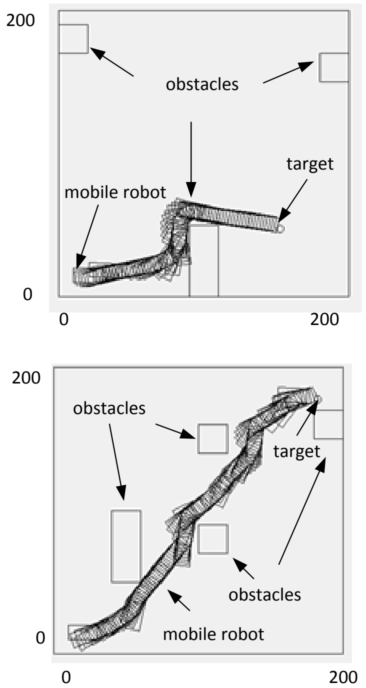

Fig. 7. X-Ypath of mobile robot with the usage of developed fuzzy–oriented method for motion modes implementation at cluttered environment

Fig. 7 shows the effectiveness of proposed motion control system with developed method for motion modes implementation of mobile robot at cluttered environment.

3. Conclusions

Behavior-Based Control is proposed for motion control system implementation with the usage of four motion modes. It gives the possibility to reach the target without collision with obstacles and to adapt the robotic system for performing any tasks by adding additional modules. A method for determining the effective rotation angle of mobile robot is proposed as a linear combination of rotation angles which are obtained in different motion modes and activation coefficients. Such approach provides motion control of mobile robot without collisions with obstacles in uncertain environments. Fuzzy-oriented method with high accuracy and performance is used for motion modes implementation and finding values of activation coefficients which is the combination of fuzzy logic and linear regression model. Simulation result shows the effectiveness of proposed motion control system. The comparison of proposed fuzzy-oriented method with Mamdani FIS for implementation of each motion mode shows that movement of mobile robot is more accurate with using proposed fuzzy-oriented method.

References

[1] Arena P., Fortuna L., Frasca M., Patané L., Pavone M.: Towards autonomous adaptive behavior in a bio-inspired CNN-controlled robot, Proceedings of the IEEE International Symposium on Circuits and Systems ISCAS 2006.

[2] Benbouabdallah K., Qi-dan Z.: A Fuzzy Logic Behavior Architecture Controller for a Mobile Robot Path Planning in Multi-obstacles Environment Research, Journal of Applied Sciences, Engineering and Technology, 5(14), 2013, 3835-3842.

[3] Cherroun L., Boumehraz M.: Designing of Goal Seeking and Obstacle Avoidance Behaviors for a Mobile Robot Using Fuzzy Techniques, J. Automation & Systems Engineering, 6-4, 2012, 164-171.

[4] Chonnaparamutt W., Birk A.: A Fuzzy Controller for Autonomous Negotiation of Stairs by a Mobile Robot with Adjustable Tracks, RoboCup 2007: Robot WorldCup XI, Lecture Notes in Articial Intelligence (LNAI), Springer, 2008.

[5] Cruz D., McClintock J., Perteet B., Orqueda O., Cao Y., Fierro R.: Decentralized cooperative control: A multivehicle platform for research in networked embedded systems, IEEE Contr. Syst. Mag., vol. 27, no. 3, 2007, 58–78.

[6] Egerstedt M.: Control of Autonomous Mobile Robots, Birkhäuser, Cambridge 2005.

[7] Grassi V. J., Parikh S. P., Okamoto Junior J.: Hybrid Delibera-Tive/Reactive Architecture For Human-Robot Interac-Tion, ABSM Symposium Series in Mechtronics, Vol. 2, 2006, 563-570.

[8] Korsunskiy V. A.: Povysheniye effektivnosti mobil'nykh robotov putem ispol'zovaniya dopolnitel'nogo istochnika energosnabzheniya – makhovichnogo akkumulyatora energii, Nauka i obrazovaniye, No. FS77-48211/2013, 125-134, (in Russian) DOI: 10.7463/0513.0566233.

[9] Leyden M, Toal D., Flanagan C.: A Fuzzy Logic Based Navigation System for a mobile Robot, Automatisierungs symposium Wismar, 1999.

[10] Nakhaeinia D., Tang S. H., Mohd Noor S. B., Motlagh O.: A review of control architectures for autonomous navigation of mobile robots, International Journal of the Physical Sciences, Vol. 6(2), 2011, 169-174.

[11] Nattharith P.: Fuzzy logic based control of mobile robot navigation: A case study on iRobot Roomba Platform, Scientific Research and Essays, Vol. 8(2), 2013, 82-94.

[12] Nazari D., Abadi M., Khooban M.H.: Design of optimal Mamdani-type fuzzy controller for nonholonomic wheeled mobile robots, Journal of King Saud University–Engineering Sciences, 05/2013, 1-9.

[13] Senthilkumar K. S.: A Study of Behavior-based and Role-based Autonomous Multi-Robot Exploration and Coverage Systems, International Journal of Latest Research In Engineering and Computing (IJLREC), Vol. 1/2013, 12-20.

[14] Tkatchenko O.: Rule-based Fuzzy System of Improved Accuracy, Conference proceedings: 56th International Scientific Colloquium (IWK): Innovation in Mechanical Engineering - Shaping the Future, 2011.

[15] Tkatchenko O.: T-Controller Workshop User Manual: Sapienware Corporation, 2011.

[16] Yegorov I.N., Kadkhim D.A.: Primeneniye mobil'nykh robotov pri vnutritrubnoy diagnostike truboprovodov s peremennym poperechnym secheniyem, Neftegazovoye delo, No. 3, 2011, 73-83 (in Russian).

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