The agent, state-space model of the mobile robot

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Abstract: The paper is devoted to present a new agent model of wheeled mobile robot. The proposed model based on nonlinear state space, discrete model of kinematics and employes Braitenberg algorithm to control the robot during move to target with passing obstacles. As a real robot the Khepera robot with IR proximity sensors was considered. The proposed agent model can be generalized onto another similar classes of devices. Results of experiments show that the proposed model correctly describes the behaviour of real device during realization of different jobs, for example obstacle passing.

Keywords: mobile robot, trajectory planning, agent model, design pattern, Braitenberg algorithm

1. Introduction

Trajectory planning in unknown environment is one of the crucial problems in mobile robotics. Mobile robot trajectory planning under constraints for partial and full coverage of given field was considered in [3]. Braitenberg algorithm based trajectory planning was considered in [5]. Specific case of path planning in picture drawing application was described in [10]. Following predefined trajectory autonomous robot in indoor transportation was presented in [11]. Same authors considered also manipulator trajectory of reconfigurable mobile robot in [12]. Quantum behaved Particle Swarm Optimization approach in trajectory planning was presented in [13].

The use of agent-based approach in modeling of mobile robots is caused by the fact that mobile robot interacts with unknown environment and often co-operates with another devices. This approach employes also well-known architecture and design patterns, able to describe different systems independently on technical details. The embodied agent model is typically decomposed to functional subsystems, which can be described independently. Additionally, the simple agent can be also easily employed to modeling a team of cooperating agents.

This approach has been considered by many authors, for example [1] where authors considered multi-agent systems where each agent has another specified task to accomplish. Person-following robot modeling case with the use of agent-based approach has been described in [6]. Fundamental for this paper use and definition of embodied-agent has been introduced in [14–16]. Fundamentals of control algorithm employed in this paper have been given by Braitenberg [2], the Braitenberg algorithm has been also discussed in [4]. The broad study about models of mobile robots has been given in [9].

Typically, agent models of mobile robots use artificial intelligence (AI) methods: knowledge engineering, knowledge based models, neural networks etc. The verification and validation this class of models requires a big number of experimental data and a huge number of calculations. The authors of this paper do not know agent-based model employing state space approach. The state-space model of robot kinematics is most accurate and it allows to analyse the fundamental properties: stability and controllability with the use of well-known mathematical tools and results of this analysis are accurate and unique.

This paper is intented to propose a new, agent based model of two wheeled mobile robot. The proposed approach employes the nonlinear, discrete state space model describing the kinematics of the Khepera III robot with IR proximity sensors, proposed in [5]. The work of IR proximity sensors is described by the interval Mittag-Leffler function (see [8]). The job of the robot under consideration is to drive from starting point to target with passing unknown obstacles detected by sensors or detect and reach an attractor, which localization is not exactly known. Additionally the robot is required to work correctly when some of sensors do not work properly.

The approach proposed in this paper bases on general, agent model of a robotic system given in paper [16]. It is able to describe different classes of robots and its idea consists in divide the robot into main functional parts realizing partial jobs associated to main job executed by a robot. Generally there are receptors, effectors and control system, connected in order to realize certain jobs. Algorithm realized by each part of agent is described by a state graph and transition functions. The work of robot determined by different conditions (for example: typical work and error detection) is expressed by behaviours.

The paper is organized as follows: at the beginning some preliminaries are given and the state space model of robot kine-

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Artykuł recenzowany
nadesłany 10.07.2018 r., przyjęty do druku 27.08.2018 r.

matics is presented. Next the proposed agent model of the robot under consideration is given. Finally the simulations covering the ride of robot to target with passing obstacles presented and going to attractor are and discussed.

2. Preliminaries

2.1. Braitenberg algorithm

The fundamental algorithm for control of simple two wheeled vehicle has been proposed by Braitenberg [2]. Its idea consists in direct connection between sensors and actuators. Each connection has got assigned some weight. Its "classic" version does not assume the motion to target but in real case this needs to be always considered. This implies that in further considerations the modified algorithm will be employed. The scheme of robot moving with the use of the modified algorithm is shown in figure 1.

2.2. State-space kinematics model of the considered mobile robot

The proposed state space model is required to describe Khepera III mobile robot equipped with IR proximity sensors employed to recognize the environment and localize obstacles. The state-space model of its kinematics has been proposed and analysed in [5]. Localization of drives and sensors for the considered robot is shown in figures 2 and 3.

Kinematics equation describing a motion of robot is defined as follows:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \\ \dot{\varphi}_1 \\ \dot{\varphi}_2 \end{bmatrix} = \begin{bmatrix} \sin\theta & 0 \\ \cos\theta & 0 \\ 0 & 1 \\ \frac{-1}{r} & \frac{-l}{r} \\ \frac{1}{r} & \frac{-l}{r} \end{bmatrix} \cdot \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \qquad (1)$$

where: x, y – current position the center of robot in global coordinate system, θ – angle between local coordinate system involved with robot and global coordinate system, φ_1, φ_2 – angle position of left and right wheel of robot, u_1 – linear speed of robot, u_2 – speed of change robot orientation, l – half of distance between two wheels, r – radius of robot wheel.

It is possible to formulate the state equation for speeds u_1 and u_2:

$$u_1 = r \cdot \frac{\dot{\varphi}_2 - \dot{\varphi}_1}{2} \qquad (2)$$

$$u_2 = -r \cdot \frac{\dot{\varphi}_2 + \dot{\varphi}_1}{2} \qquad (3)$$

After transformation (1) we obtain formula between constituent of whole robot velocity and velocity of each wheel

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \frac{r \cdot \sin\theta}{2} & \frac{-r \cdot \sin\theta}{2} \\ \frac{-r \cdot \cos\theta}{2} & \frac{r \cdot \cos\theta}{2} \\ \frac{-r}{2} & \frac{-r}{2} \end{bmatrix} \cdot \begin{bmatrix} \dot{\varphi}_1 \\ \dot{\varphi}_2 \end{bmatrix} \qquad (4)$$

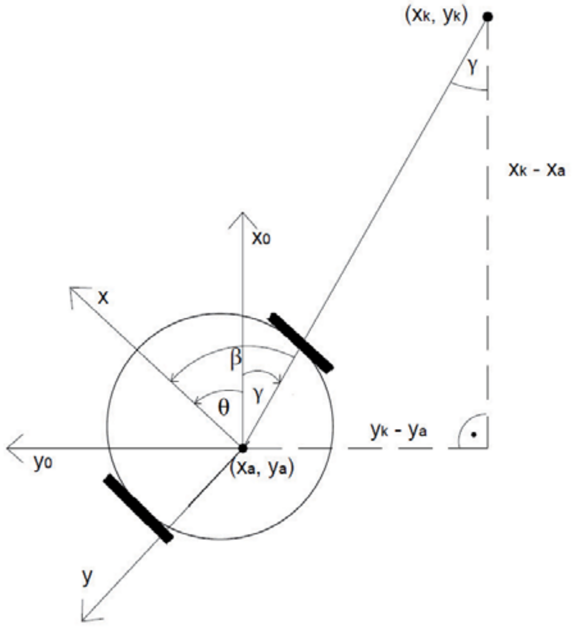

Fig. 1. Modified Braitenberg algorithm
Rys. 1. Zmodyfikowany algorytm Braitenberga

With respect to modified Braitenberg algorithm, velocities of each wheel are described as follows:

$$\omega_L = \sum_{n=1}^{4} \omega_n u_n - \sum_{n=5}^{8} \omega_n u_n + K + M\beta.$$
$$\omega_R = -\sum_{n=1}^{4} \omega_n u_n + \sum_{n=5}^{8} \omega_n u_n + K - M\beta. \qquad (5)$$

where M is the weight of coefficient responsible for correct wheels velocity due to deviation between current direction of robot motion and straight line getting across the center of robot and target point, β is the angle between current direction of robot motion and straight line getting across the center of robot and target point, K is the base velocity of each wheel. It is necessary to assure the motion of the robot when there are no obstacles detected by sensors. In the figure 1 it can be noted that:

$$\beta = \theta - \gamma$$

$$\gamma = \arctan \frac{y_k - y}{x_k - x}.$$

$$\theta = r\left(\sum_{n=1}^{4} \omega_n u_n - \sum_{n=5}^{8} \omega_n u_n + M\beta \right). \qquad (6)$$

$$\theta = r\left(\sum_{n=1}^{4} \omega_n u_n - \sum_{n=5}^{8} \omega_n u_n + M\theta - M \arctan \frac{y_k - y}{x_k - x} \right).$$

In the case of defined target (modified Braitenberg algorithm) the following relationship is kept:

$$\theta = \grave{u} \;= r\left(\sum_{n=1}^{4} \omega_n u_n - \sum_{n=5}^{8} \omega_n u_n + M\theta - M \arctan \frac{y_k - y}{x_k - x} \right). \qquad (7)$$

Finally the model of robot kinematics with defined target takes the form as below:

$$\begin{cases} \dot{x} = \dfrac{Kr}{l}\cos\theta \\ \dot{y} = \dfrac{Kr}{l}\sin\theta \\ \theta = r\left(\displaystyle\sum_{n=1}^{4}\omega_n u_n - \sum_{n=5}^{8}\omega_n u_n + M\theta - M\arctan\frac{y_k - y}{x_k - x}\right) \end{cases} . \qquad (8)$$

The robot path calculated as solution of (8) is required to meet the following constraints:

1. start from point $(0,\ 0,\ \theta_0)$,
2. finish in point $(x,\ y,\ \theta)$,
3. cannot across any obstacle.

In order to proceed with further investigation, there is a need to transform continuous-time non-linear equation (8) to its discrete version. The simplest way to do it is to apply the Euler backward difference: $\dot{x} \cong \dfrac{x(k) - x(k-1)}{h}$. If the nonlinear model in continuous time scope is described by (8), then the discrete state of the agent ${}_{r}^{e}c^{k}$ takes the following form:

$${}_{r}^{e}c^{k} = \left[x(k), y(k), \theta(k)\right]^{\mathrm{T}} \qquad (9)$$

where:

$$\begin{cases} x(k) = x(k-1) + \dfrac{hKr}{l}\cos\theta(k-1) \\ y(k) = y(k-1) + \dfrac{hKr}{l}\sin\theta(k-1) \\ \theta(k) = hr\left(\displaystyle\sum_{n=1}^{4}\omega_n u_n(k-1) - \sum_{n=5}^{8}\omega_n u_n(k-1) + M\theta(k-1) - M\arctan\frac{y_k - y(k-1)}{x_k - x(k-1)}\right) \end{cases} . \qquad (10)$$

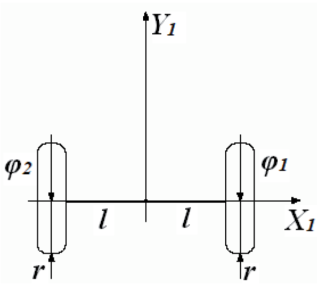

Fig. 2. Drive configuration in the considered robot
Rys. 2. Konfiguracja napędów w rozważanym robocie

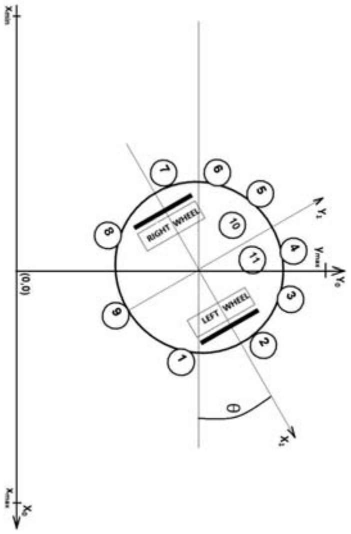

Fig. 3. Sensors configuration in the considered robot
Rys. 3. Konfiguracja czujników w rozważanym robocie

In (10) h denotes the sample time, k denotes discrete time moments. The nonlinear, discrete state equation (10) directly connects signals read by IR sensors with control signals sent to drives. It can be utilized to construct the agent model of the considered robot with respect to formal approach given in [16]. This will be shown in the next section.

3. The proposed agent model

The agent model of Khepera robot shown in figures 1 and 3 can be presented as the following set:

$$A = \{\ P_n,\ E_m,\ p_n,\ e_m,\ c,\ f\,\} \qquad (11)$$

where P and E are real receptors and effectors, p and e are sets of virtual receptors and effectors, c is a control system and f is a nonlinear transition function.

Real receptors P_n, $n = 1, \ldots, 8$ are IR sensors, real effectors $E_{R,L}$ are the angular velocities of wheels (index R denotes the right wheel, L denotes left one), the control subsystem is described by a nonlinear transition function, derived from state equation (8) after necessary transformations.

The dependence between real and virtual receptors in the k-th time moment is following:

$${}_{P}^{c}p_n^k = \left(\sum_{n=1}^{4}\omega_n P_n^k - \sum_{n=5}^{8}\omega_n P_n^k\right), \quad n = 1, \ldots, 8. \qquad (12)$$

Next the transition function f needs to be defined. It has 3 components, associated with state variables in equation (10):

$$f^k = \left[f_x^k,\ f_y^k,\ f_\theta^k\right]^{\mathrm{T}} \qquad (13)$$

where:

$$\begin{aligned} f_x^k &= x(k) \\ f_y^k &= y(k) \\ f_\theta^k &= \theta(k) \end{aligned} \qquad (14)$$

With respect to (10) the transition function takes the following form:

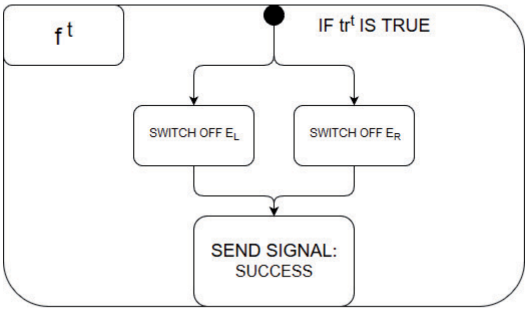

Fig. 4. Arrival to target function
Rys. 4. Funkcja osiągnięcia celu

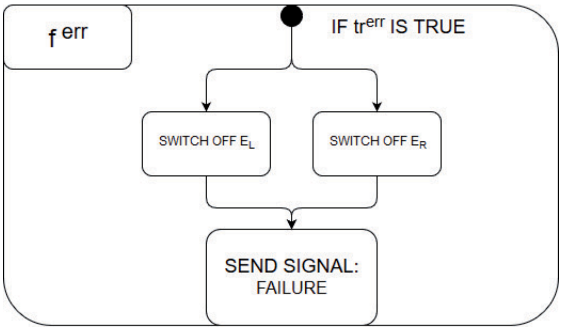

Fig. 5. Error function
Rys. 5. Funkcja błędu

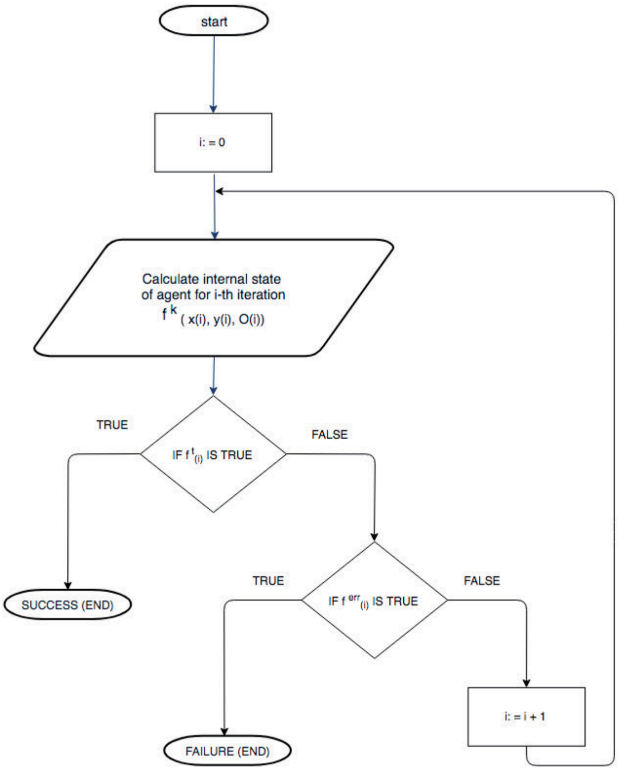

Fig. 6. Flow chart of system behavior
Rys. 6. Schemat blokowy zachowania się systemu

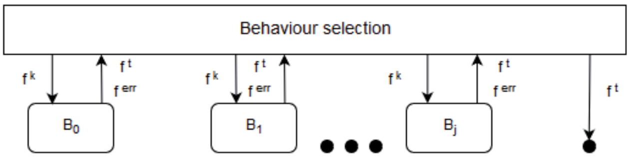

Fig. 7. State graph for considered system
Rys. 7. Graf stanu dla rozważanego systemu

$$\begin{cases} f_x^k = f_x^{k-1} + \dfrac{hKr}{l}\cos f_\theta^{k-1} \\[2ex] f_y^k = f_y^{k-1} + \dfrac{hKr}{l}\sin f_\theta^{k-1} \\[2ex] f_\theta^k = hr\,{}_P^c p_n^k + M f_\theta^{k-1} - M\arctan\dfrac{f_y^k - f_y^{k-1}}{f_x^k - f_x^{k-1}} \end{cases} \tag{15}$$

The virtual effectors ${}_c^E e_n^k$ in k-th moment are following:

$$\begin{gathered} {}_c^E e_L^k = \sum_{n=1}^{4} \omega_n p_n^k - \sum_{n=5}^{8} \omega_n p_n^k + K + M\beta \\ {}_c^E e_R^k = \sum_{n=1}^{4} \omega_n p_n^k + \sum_{n=5}^{8} \omega_n p_n^k + K - M\beta \end{gathered} \tag{16}$$

Real effectors are directly equal to virtual:

$${}_e E_m^k = {}_c^E e_m^k, \quad m = R,\ L. \tag{17}$$

The job of the robot is to drive from starting point c^0 to target c^τ with passing unknown obstacles. This job cannot be realized, if an obstacle is not possible to pass. This can should be defined as an anomalous situation. Consequently the behaviour B of the considered robot can be expressed by 3 functions:

$$B = \{f^d, f^\tau, f^{err}\} \tag{18}$$

In the first one $f^d = f^k$ describes the ride of robot with successful passing obstacles, the next one f^τ defines activities in case of arrival to target and the last one f^{err} describes situation, when obstacle cannot be passed.

Definitions of f^τ and f^{err} are presented accordingly in figures 4 and 5.

In case of both functions, there is a need to define triggers which are responsible for execute those functions when specific event (condition of agent) will be observed. Condition which triggers arrival to target function (tr^t) is defined as follows:

$$tr^t = \sqrt{\left(f_x^k - x(0)\right)^2 + \left(f_y^k - y(0)\right)^2} \le d \tag{19}$$

Where d is arbitrary defined value which indicates maximal distance of robot from the target. Condition which triggers error state of considered agent (tr^{err}) is defined as follows:

$$tr^{err} = f_x^k - f_x^{k-1} = f_y^k - f_y^{k-1} = f_\theta^k - f_\theta^{k-1} = 0 \tag{20}$$

When lack of any movement (of robot) between last and current state has been confirmed, error behaviour is executed.

General flow chart of considered system behaviour is presented in figure 6. State graph of the behaviour selection automaton is presented in figure 7. Inner structure of agent considered for Khepera robot was prepared with the manner described in [16] and is presented in figure 8.

The above, nonlinear, discrete time agent based model can be employed to modeling of the behaviour of the considered mobile robot. It can be verified with the use of simulations. This will be shown in the next section.

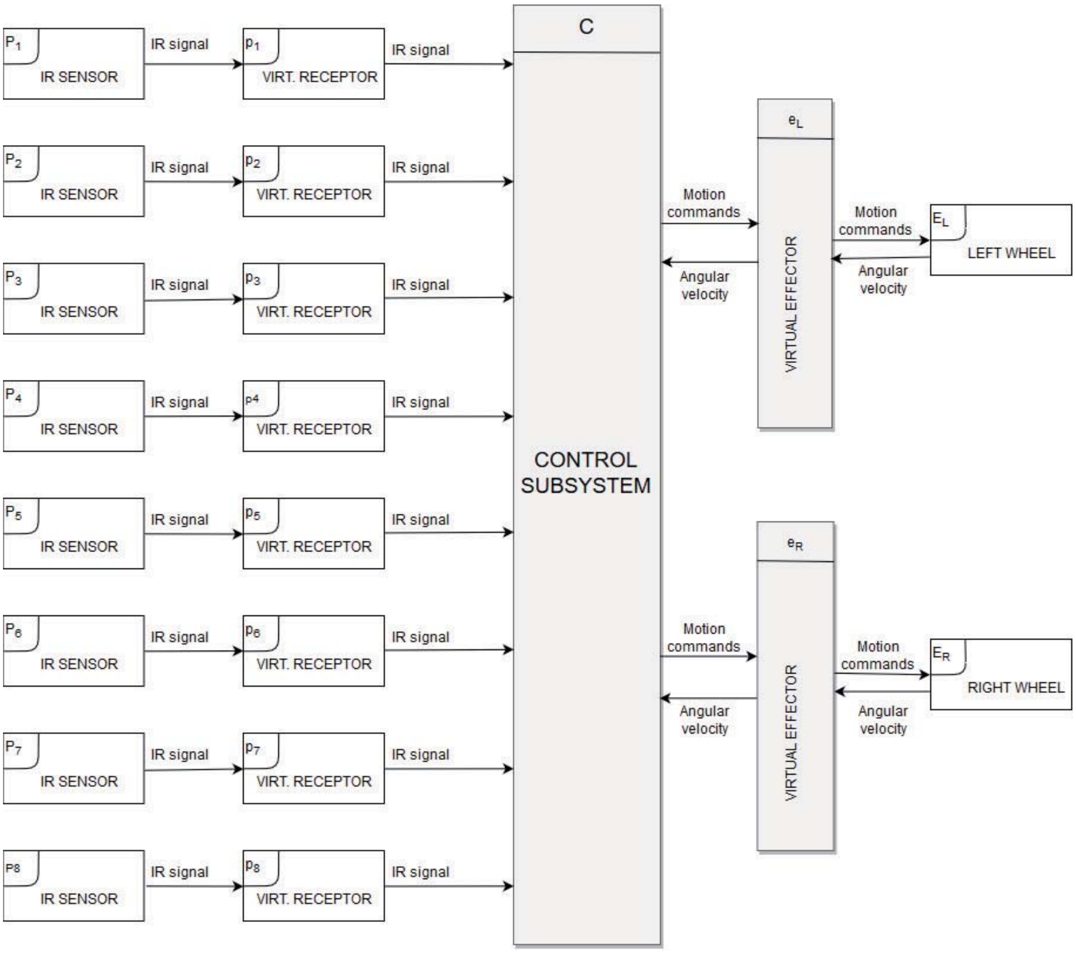

Fig. 8. Structure of considered agent representing robot Khepera
Rys. 8. Struktura agenta reprezentującego robot Khepera

4. Simulations

Simulations were done using the discrete agent model expressed by (10) and Simulink model shown in figure 9. Results of simulations with defined target are illustrated by figures 10, 11, 12 and 13. Results of simulations with single attractor as target are illustrated by figures 14, 15, 16 and 17.

Simulink model presented in figure 9 accepts two vectors as parameters: w weights of sensors in considered system and u value detected by specified sensor. Outputs of described model are calculated local coordinates of considered robot (x, y).

Simulations with defined target covers two types of obstacle shapes: circle and wall (oblong shape) and two types of colors: black and white. Reflection of infrared is much lower in case of black obstacle than in case of white obstacle.

Accordingly simulations with black colored obstacles presented in figures 11 and 13, occurs to calculate mobile robot trajectory in a way, which is interfering with position of placed obstruction object. Tests with a clear path of calculated trajectory are presented in figures 10 and 12.

From the above figures it can be concluded at once that the color of the obstacle can significantly disturb the correct work of the robot we deal with. This is caused by the idea of work IR proximity sensors applied in the considered robot. The black obstacle absorbs radiation emitted by sensor and the robot is not able to correctly recognize it. It was also observed during experiments with real robot (see [5]).

In case of simulations covering single attractor as potential target it can be noticed that trajectory of mobile robot is calculated correctly. Weights determined by w parameter are key factors in this type of simulation. Having sufficient impact on proper u value it makes model calculating suitable path in considered environment. It can be noticed that size of obstacle has impact on calculated trajectory. In figures 16 and 17 presenting bigger size of obstacles, robot receptors are more efficient in finding nearest edge of considered shape.

5. Final conclusions

The main final conclusion from the paper is that the proposed agent model employing nonlinear, discrete state equation correctly describes the behaviour of the real mobile two wheeled robot. Problems with passing the black obstacle are also correctly modeled.

Searching for attractor in defined environment is also correctly modeled. This area of research can be still explored with the use of additional algorithms covering individual handling of weights for each input to the considered system. The another open problems from the presented area cover for example the modeling of cooperation a team of mobile robots described by the proposed model, work of robot with damaged sensors and so on. This will be considered by authors.

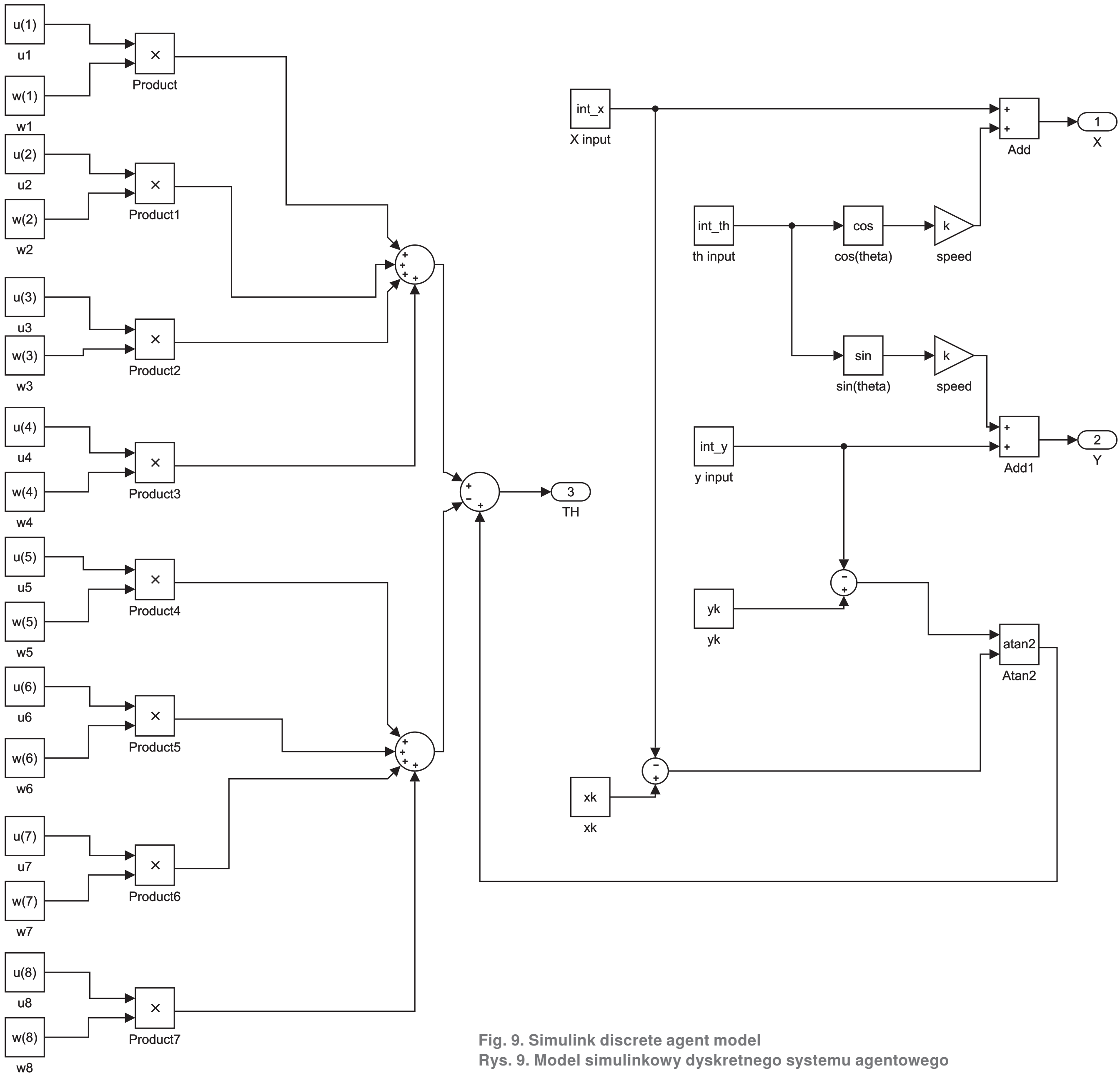

Fig. 9. Simulink discrete agent model
Rys. 9. Model simulinkowy dyskretnego systemu agentowego

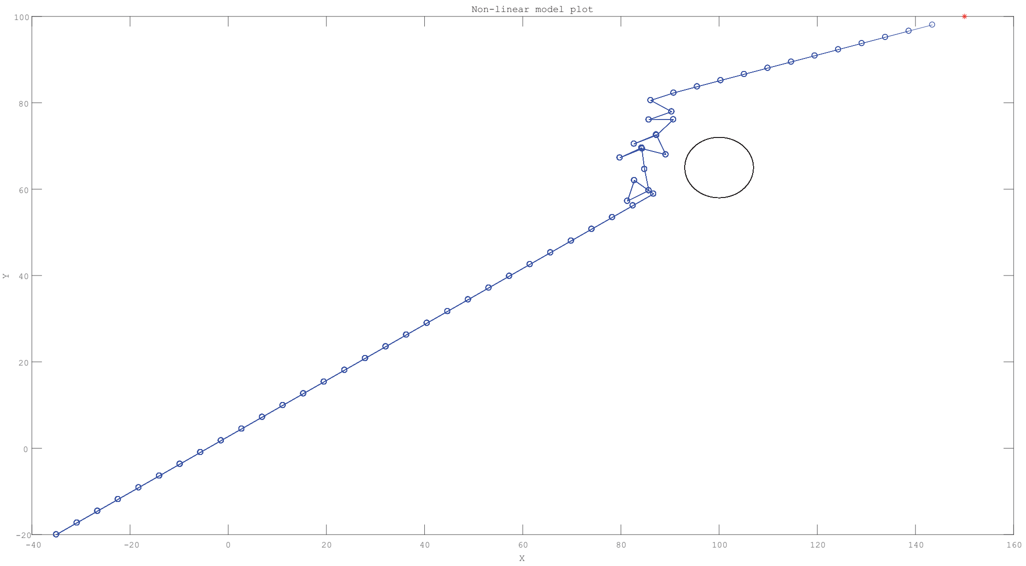

Fig. 10. Obstacle as white circle
Rys. 10. Test ominięcia przeszkody w postaci białego okręgu

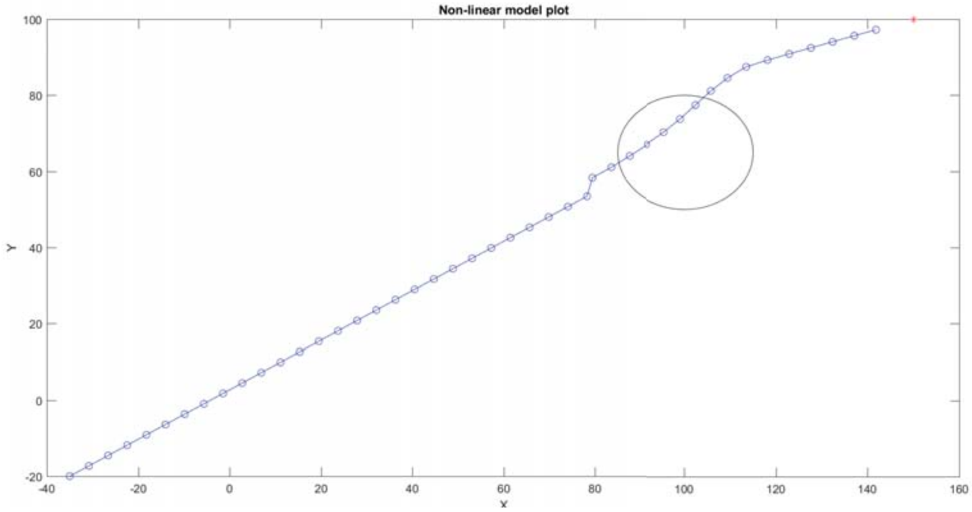

Fig. 11. Obstacle as black circle
Rys. 11. Test ominięcia przeszkody w postaci czarnego okręgu

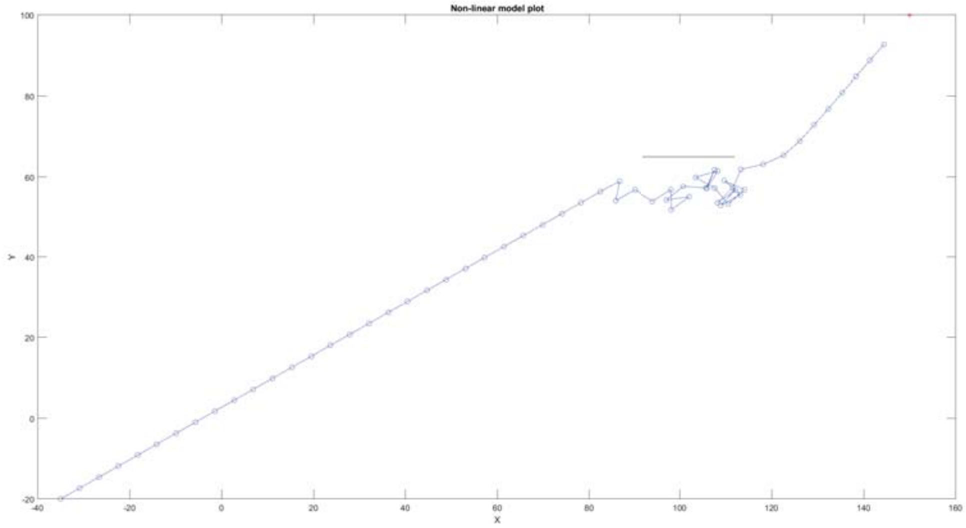

Fig. 12. Obstacle as oblong white shape
Rys. 12. Test ominięcia przeszkody w postaci białego kształtu

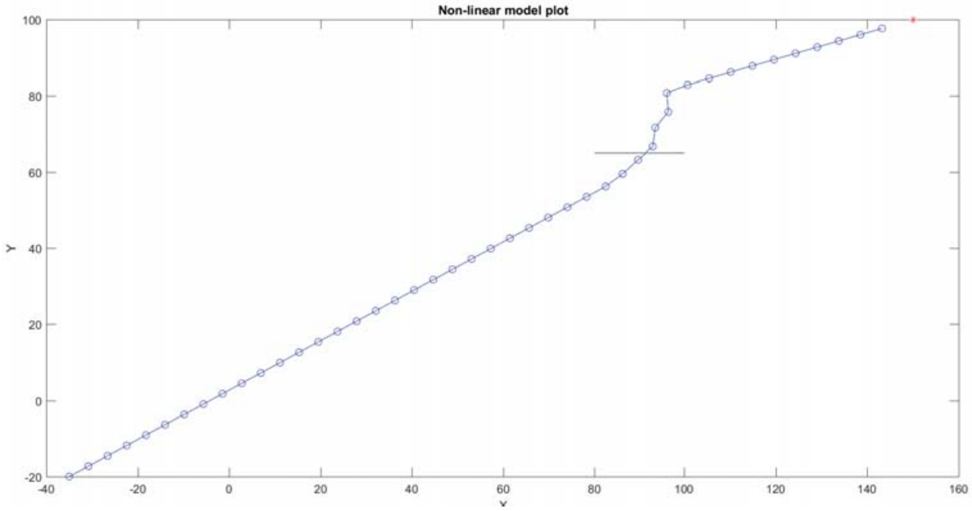

Fig. 13. Obstacle as oblong black shape
Rys. 13. Test ominięcia przeszkody w postaci czarnego kształtu

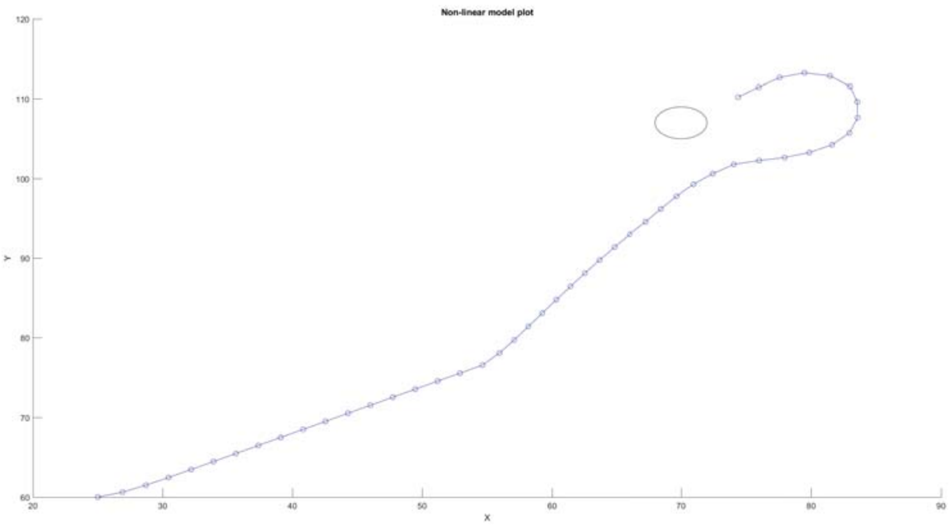

Fig. 14. Attractor as small circle
Rys. 14. Test jazdy do atraktora w postaci małego okręgu

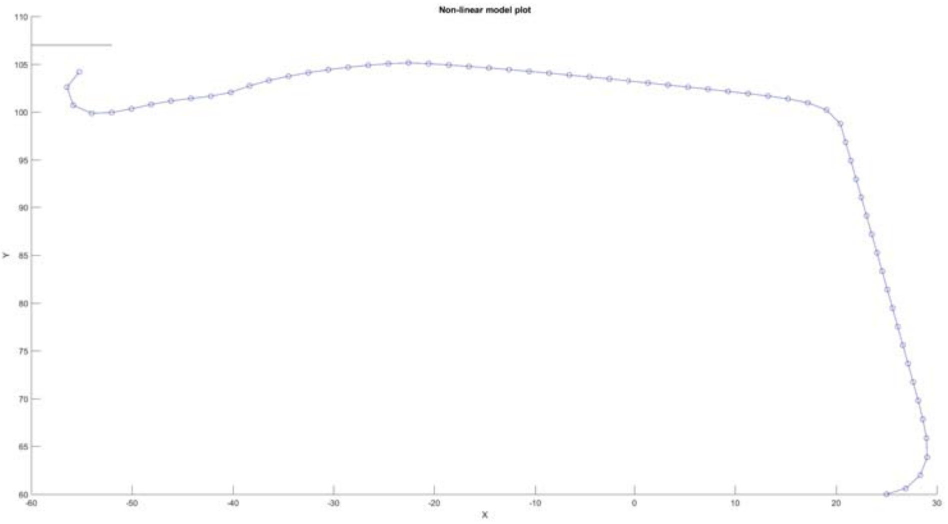

Fig. 15. Attractor as short oblong shape
Rys. 15. Test jazdy do atraktora w postaci małego podłużnego kształtu

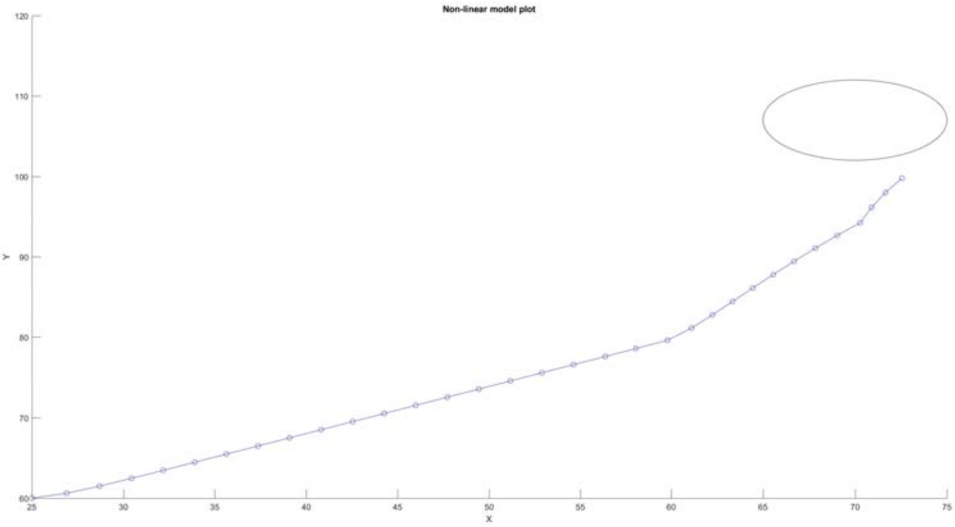

Fig. 16. Attractor as bigger circle
Rys. 16. Test jazdy do atraktora w postaci większego okręgu

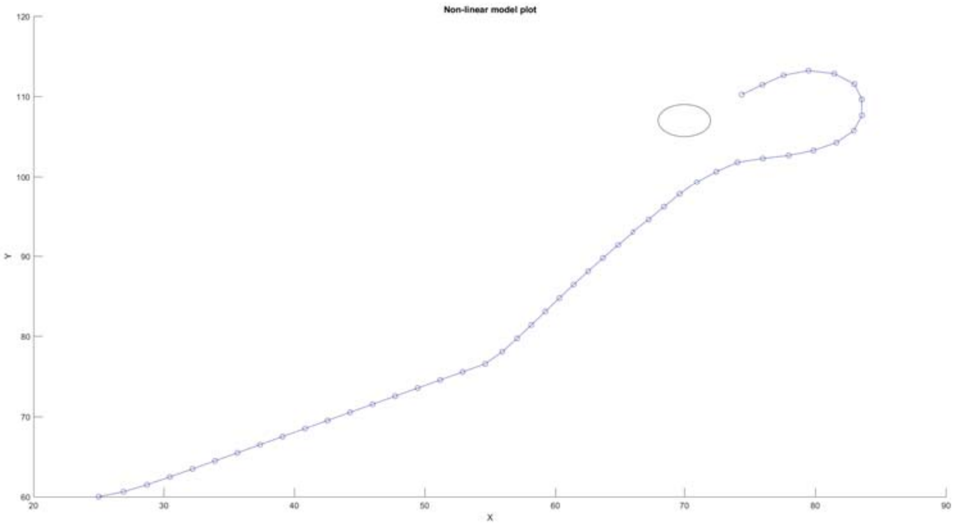

Fig. 17. Attractor as longer oblong shape
Rys. 17. Test jazdy do atraktora w postaci dużego podłużnego kształtu

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Agentowy model robota mobilnego w przestrzeni stanu

Streszczenie: W artykule zaprezentowano nowy model agentowy kołowego robota mobilnego. Proponowany model bazuje na nieliniowym równaniu stanu opisującym kinematykę robota i wykorzystuje algorytm Braitenberga z zadanym punktem końcowym w celu omijania przeszkód. Jako przykład rzeczywistego robota rozważono robot Khepera III z czujnikami IR do wykrywania i omijania przeszkód. Zaproponowany model agentowy może być uogólniony na inne klasy podobnych urządzeń. Wyniki symulacji pokazują, że zaproponowany model dobrze opisuje zachowanie się rzeczywistego urządzenia podczas realizacji różnych zadań, np. przy omijaniu przeszkód.

Słowa kluczowe: robot mobilny, planowanie trajektorii, model agentowy, wzorce projektowe, algorytm Braitenberga

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