# Odometers Error Estimation of the Two-Wheeled Mobile Robot

**Valery Kasyanik[1), Ivan Dunets[2), Andrew Dunets[3)**

1) Brest State Technical University, Brest, Moskovskaja,267, val.tut@gmail.com
2) Brest State Technical University, Brest, Moskovskaja,267, ivandunets@gmail.com
3) Brest State Technical University, Brest, Moskovskaja,267, dunets@gmail.com

***Abstract:*** *This article considers the approach of using of a neural network to estimate the odometry error in the mobile robot localization based on the odometers. As the odometers were used inexpensive optical odometers with a resolution of 48 counts per wheel revolution. Data obtained from the odometer using for calculating the position of the robot by means of a mathematical model of its differential kinematic schemes. Odometers data are also used for training the neural network. For training the neural network was used the trajectory of the robot as the reference data, obtained through chart pattern recognition system is mounted on the robot.*

***Keywords*****:** mobile robot, odometry error, neural network

**1. INTRODUCTION**

In the laboratory of robotics of BrSTU there are mobile robots developed, which are intended for solving different practical tasks. Among them: a robot-guide (fig.1), an intellectual robotic platform, a robot-guard (fig.1), a robot for education, a robot for participation in competitions "Roborace" (fig.2). All of these projects of the robots are constructed on the basis of a platform with differential kinematical scheme. Use of it is due to the simplicity, reliability and cheapness, but in the real conditions there is a problem of determination of exact location of robot.


**Fig. 1 Robot-guide(left), Robot-guard**

For solving the problem of positioning it can be used several different methods. These approaches are presented in [1-5]. However they require the presence of expensive sensors (laser scan) or a powerful onboard computer for realization of complicated algorithms.

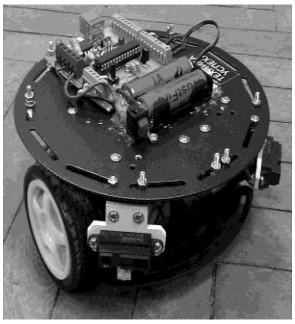


**Fig. 2 Robot for race competition "Roborace"**

The robots, which have been developed in the laboratory of robotics, as a rule, are equipped by inexpensive and available sensors (IR-range finder, ultrasonic sensor, odometers). Use of low-priced solutions makes robots accessible to widely adopted, but it causes a number of problems, which must be solved algorithmically.

Thus, for the purpose of solution of the positioning problem have been choosed odometers – the sensors of turns the wheels. Their accuracy is not high, what has a negative influense on the quality of solution of the positioning problems, navigation and other problems, which are bound up with it. In this paper it is offered to use the method, that has been proposed in [6], but taking into account features of our robots.

The primary idea of this method is in use of neural networks for estimate the size of error of odometers in time and calculation of this error when solving the problems of positioning and navigation. The above robots was developed and made in the laboratory of robotics without use of commercial solutions. That in conjunction with small linear sizes of robots increases the error of positioning system and requires more accurate mechanism of estimation of this error.

The main object of the studies described in this paper is to improve the accuracy of positioning systems of real mobile robot based on using of the methods of artificial neural networks. However, the using of odometers for positioning the robot in space is related to the problem of rapidly accumulating error caused by different factors. In detail the problem of odometer error is presented in [5].

**2. SPECIFICATION OF THE ROBOT**

In the experiments has been used a two-wheeled very small (13 cm) mobile robot platform, equipped with odometers on each wheel, two infrared distance measured sensors, Wi-Fi communication module. The robot platform is shown in Figure 3. Robot has differential kinematics with two ball support wheels. As the odometer are used optical encoders with a resolution of 48 counts per wheel revolution. The size of the wheelbase of 8.825 cm for the experiments used infrared sensors distances Sharp with a range of 10-80 cm.

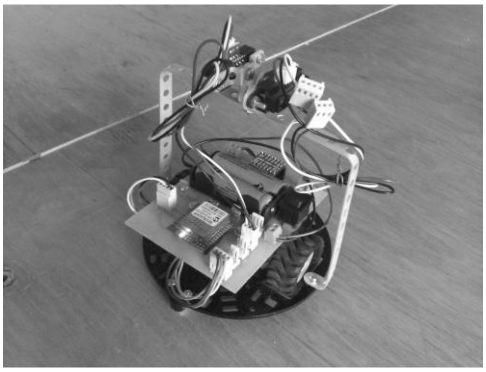


**Fig. 3 - Image of a mobile robot for experiments.**

## 3. ODOMETRY ERROR MODEL

The calculation of the current position of the robot used a mathematical model, was described below. Let the initial and final positions of the robot are given by the vectors:

$$P_0 = \begin{bmatrix} x_0 \\ y_0 \\ \theta_0 \end{bmatrix} \qquad P_1 = \begin{bmatrix} x_1 \\ y_1 \\ \theta_1 \end{bmatrix} \qquad (1)$$

Odometers can get the instantaneous velocity $v_l, v_r$ of the left and right wheels. If you know the size of the robot's wheel base b, the relationship between the initial, final coordinates of the position of the robot and the odometer data is follows:

$$P_1 = \begin{bmatrix} x_1 \\ y_1 \\ \theta_1 \end{bmatrix} = \begin{bmatrix} x_0 \\ y_0 \\ \theta_0 \end{bmatrix} + \begin{bmatrix} \frac{v_l + v_r}{2}\cos\left(\theta + \frac{v_l - v_r}{2b}\right) \\ \frac{v_l + v_r}{2}\sin\left(\theta + \frac{v_l - v_r}{2b}\right) \\ \frac{v_l - v_r}{b} \end{bmatrix} \qquad (2)$$

This dependence can be represented by the distance traveled and the total angle $\delta_{trans}, \delta_{rot}$ (Figure 4).

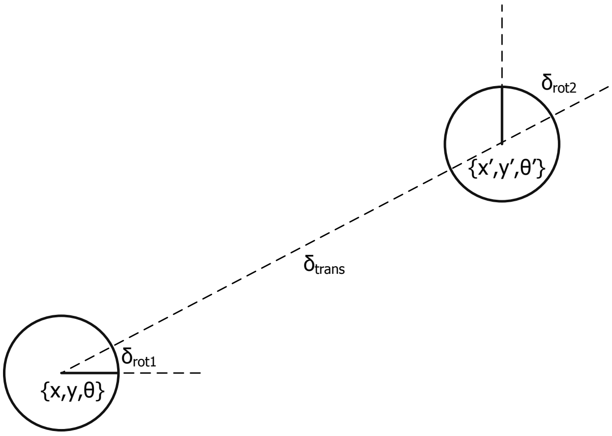



**Fig. 4 - The geometric model of the robot.**

The expressions for the distance traveled and the rotation are follows:

$$\delta_{rot} = \frac{v_l - v_r}{b}$$
$$\delta_{trans} = \frac{v_l + v_r}{2} \qquad (3)$$

Thus, the position of the robot calculated according to the next expression

$$\delta = (\delta_{rot}, \delta_{trans})$$

The error accumulated by odometers has two main components: systematic and random error. The reasons causing the systematic error are defects in the assembly mechanics and inaccuracy of designing components. Random errors caused by slippage of the wheels and uneven floors. Based on this calculation the resulting position and angle of the robot will contain these errors:

$$\hat{\delta}_{trans} = \delta_{trans} + \sigma_{trans}|d| + \varepsilon_{trans} \qquad (4)$$

$$\hat{\delta}_{rot} = \delta_{rot} + \sigma_{rot}|d| + \varepsilon_{rot} \qquad (5)$$

where $\sigma_{trans}, \sigma_{rot}$ systematic errors in estimating the distance traveled and angle of the robot, with a growing number of traversed distance $|d|$. $\varepsilon_{trans}$ and $\varepsilon_{rot}$ random errors in the distance and angle. $\hat{\delta}_{rot}, \hat{\delta}_{trans}$ actual distance traveled and the actual rotation angle.

## 4. COMPUTER VISION SYSTEM

To obtain the trajectory of motion of mobile robot was developed computer vision system. This system using for recognizing a graphical pattern, mounted on top of the robot. Applied for recognition webcam mounted on the ceiling over an area of the floor on which the experiments were performed to assess the position of the robot.

As the pattern used by a black square on a white background, centered on a black circle drawn in Figure 5. Pattern recognition is based on the detection, the image contrast of rectangles and check the black circle in the center.

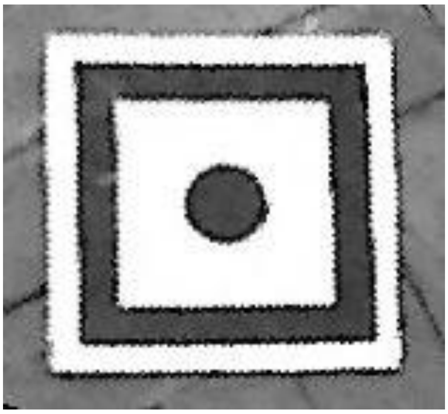


**Fig. 5 - Graphical pattern for recognition**.

Detection of the rectangles is in the shaping of images using Canny algorithm with subsequent approximation points of the contour lines. The contour is a rectangle if the following conditions: loop consists of 4 lines and the sine of the angle between the lines does not exceed 0.3.

In the interior of the rectangle allocated a path. The resulting points of the contour must defend at the same distance from the center of rectangle geometric mass, in this case, the contour will be a circle.

To improve the accuracy of the system used camera calibration to estimate the radial and tangential lens distortion. These coefficients are obtained by means of distortion image chessboard [7].

$$x^{'} = x(1 + k_1 r^2 + k_2 r^4) + 2p_1 xy + p_2(r^2 + 2x^2)$$
$$y^{'} = y(1 + k_1 r^2 + k_2 r^4) + p_1(r^2 + 2y^2) + 2p_2 xy$$

,where $r^2 = x^2 + y^2$, $k_1, k_2$ are radial distortion coefficients, $p_1, p_2$ are tangential distortion coefficients, $x^{'} y^{'}$ are undistorted image coordinates of point, $xy$ are image coordinates of point.

The coordinate positions of the robot, resulting in recognition of the pattern, was treated to remove the perspective effect in accordance with the following formula:

$$x_r = x^{'} + l\left|ox - x^{'}\right|$$
$$y_r = y^{'} + l\left|oy - y^{'}\right|,$$

where $l$ are coefficient of perspective distortion, $ox, oy$ are center of the image.

Recognition result is shown in fig. 9b.

## 5. DESCRIPTION OF NEURAL NETWORK

To estimate the increasing error is encouraged to use artificial neural network, which will predict the change in error over time. Since the odometer error depends on a variety of random and systematic factors, the change of error is a nonlinear dynamical system.

To predict the behavior of such systems and the subsequent correction of the position of the robot was used neural network with one hidden layer, which was used for training error back-propagation. The input layer of neural network consists of 10 neural elements, a hidden layer of 13, an output layer contains 2 neurons. The architecture of the neural network shown in Figure 6.

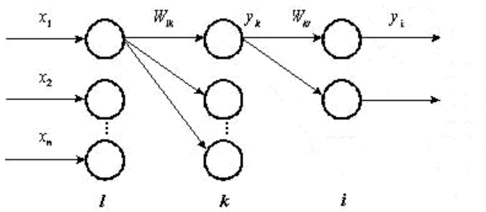



**Fig. 6 - The architecture of the neural network**

For training the neural network was used the following approach. The input to the neural network serves odometer data and the start and end of motion. The input images have a follow form:

$$\{x_1, y_1, x_2, y_2, \ldots, x_8, y_8,, t_b, t_e\},$$

where $(x_i, y_i)$ – coordinates of robot, $t_b$ , $t_e$– time of start/end experiment.

Output neurons of a neural network formed by the values of the robot in the form of coordinates ($y_x$, $y_y$) respectively. For training the neural network as the reference values used the real position coordinates of the robot – ($t_x$, $t_y$). The real position of the robot is estimated using two approaches - video recognizing of a robot with a camera mounted on the ceiling, and the data of infrared range finders.

Neural network training consist in reducing of the mean-square error E between the coordinate values obtained at the output of the network and coordinates obtained from measurements of the mobile robot with a camera:

$$E = \frac{1}{2}\sum_{k=1}^{L}\sum_{j=1}^{2}(y_j^k - t_j^{\,k})^2,$$

where $L$ are range of learning sample, $y$ - output of neural network, $t$ - etalon coordinates from computer vision system.

The architecture of the neural network was chosen empirically to obtain a preliminary assessment of the quality of forecasting error.

## 6. STATEMENT OF THE EXPERIMENTS

Traditionally, for researching the odometer error method is used UMBMark, proposed in [5]. At this stage of research experiments were conducted in a simplified form, as at the same time was carried out refinement of mechanical robot. The robot moved in a straight line along the wall at a constant speed 0.4 m/s specified amount of time. The experiments consisted in the fact that the robot was mounted on the starting position, then send the command to start the movement.

When moving the robot odometer reading was carried out at intervals of 200 ms. 8 intermediate positions of the robot was calculated with the obtained data. From this information were formed the input pattern to the neural network.

For the formation of etalon pattern required for training the neural network was used points of trajectories which obtained from system for robot recognition.

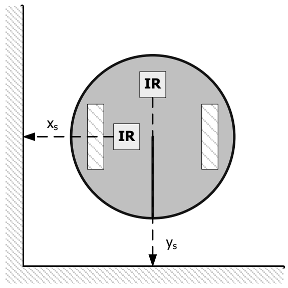



**Fig. 7 - Scheme for measuring the position of the robot with a rangefinder.**

For initial calibration of the robot reference position values were recorded using infrared rangefinders, perpendicular to one by another. In the process of calibrating the robot was moving along the wall, thus, indications of the rangefinders correspond to coordinates X, Y position of a real robot.

## 7. EXPERIMENTAL RESULTS

In the first phase of experiments was carried out the research of the characteristics of mobile robot mechanics. As a result, were received characteristics of behavior of the robot's mechanics in different conditions: a) straight-line motion on its own engines, b) the straight-line motion when the engine is in tow. Thus in Figure 8 shows plots of oscillation of instantaneous velocities of two wheels in the above described experiments. It is clear that the velocity fluctuations are present both wheels in motion mode on its own engines and towing mode. In addition, in the error are added the surface roughnesses. All experiments were performed on a surface covered with a special material to minimize the random component of error. Cameras and infrared sensors were calibrated with the object of reducing the error. Data from the infrared range finders were refined by the least squares method.

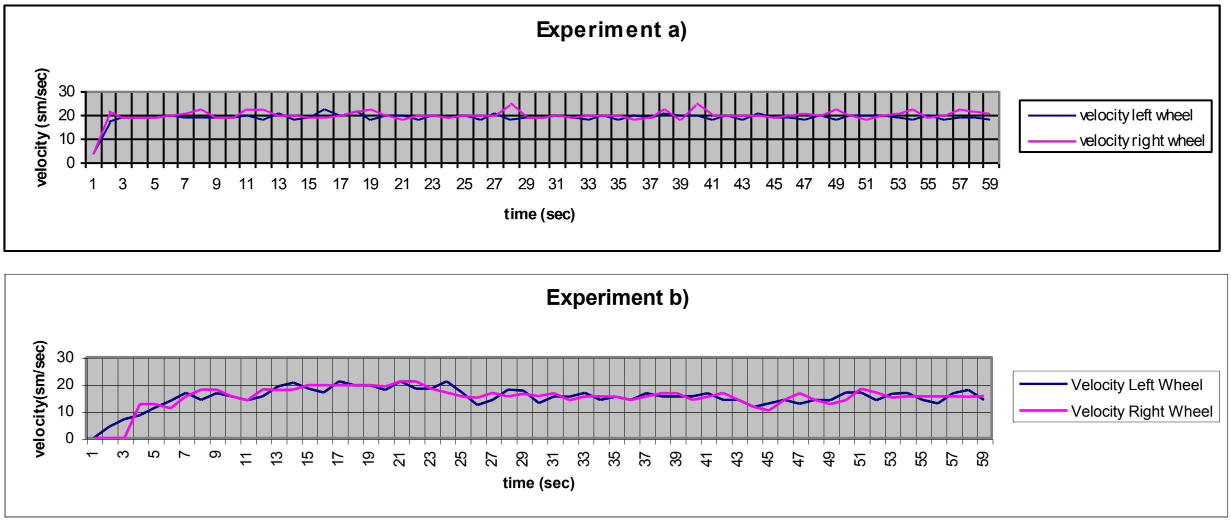
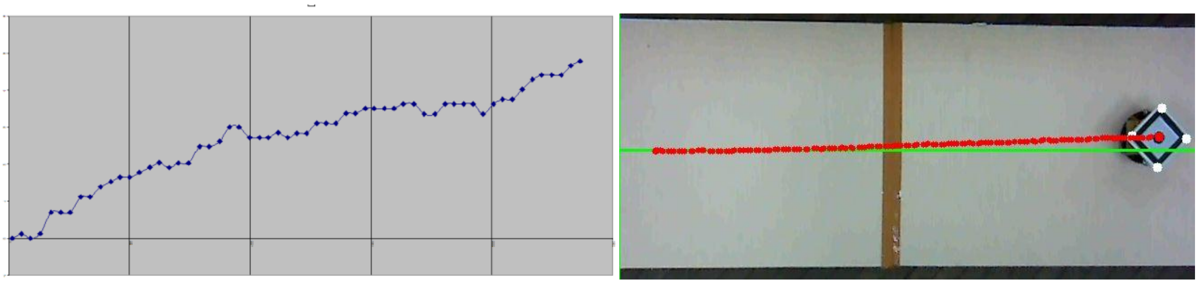



**Fig. 8 - Fluctuations in the velocity of wheels in the experiments a, b.**

After setting up the equipment and calibration there were realized experiments for obtaining a training sample. In the Figure 9a is represented the way of the robot, which is formed on the basis of odometers. In the Figure 9b is represented the path of the robot, which has been fixed with the video detector. It is clear that in time the error increases and odometers data begin to differ considerably. Fluctuations are clearly visible within the course angle of 4 degrees, that was caused by the small dimensions of the robot, namely a small wheelbase. Then is shown the effectiveness of the neural network for dynamic specification of the error and correction of the current robot's position. During the experiments, data of the position error in time were obtained. The resulting graph is shown in Figure 9.

The graph shows that at the initial time interval of 1.6 seconds to sharp jumps in error, this situation is caused by the uneven inclusion of each of the engines, which leads to an error in addition to various factors such as race and interference power in the food chain odometers, a strong slipping wheels while turning the engine, etc.



**a)** **b)**

**Fig. 9 - a) the path of the robot based on the odometer, and b) the actual path the robot.**

After stabilization of the engines, leveling of odometers vibration errors within the constant value takes place. Constant component provides by a systematic error, which is added regularly to the values of the position. Fluctuations are provided by the random component of error. Because of using special surface the random component is less than 1 cm.

The neural network that was describe above has been used for prediction of this graph. After training the neural network there were obtained results that are presented in Figure 11. In the process of forecasting errors odometer changes to the architecture of the neural network was obtained the probability of 84%.

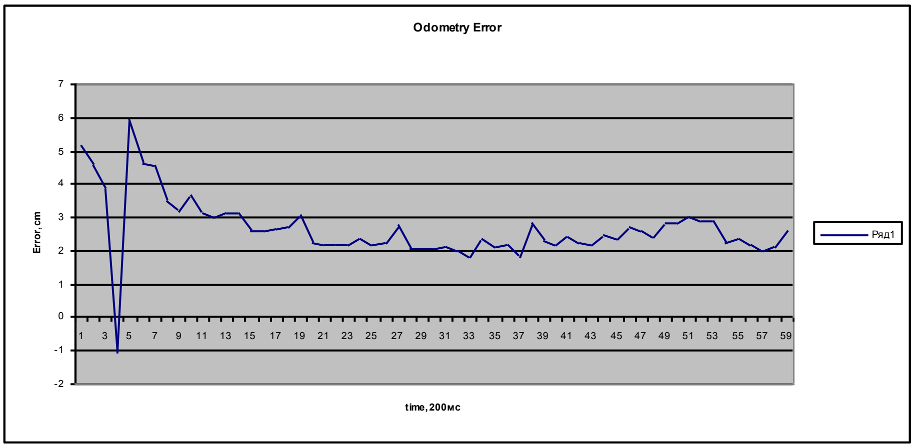



**Fig. 10 – The schedule change odometer error over time.**

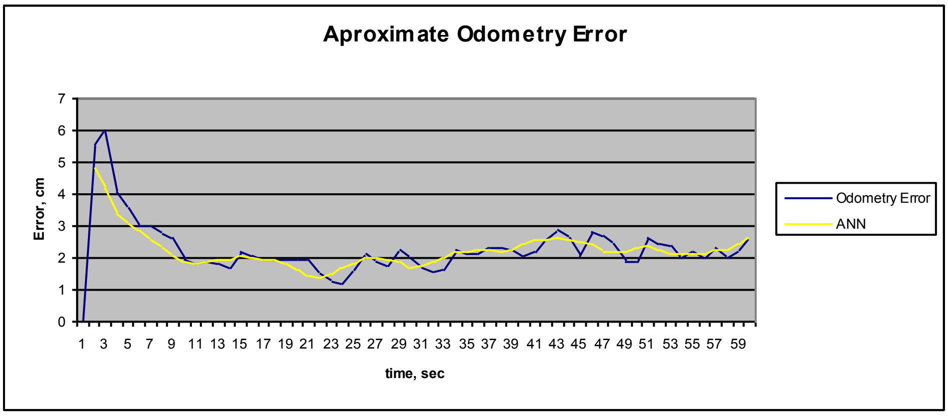



**Fig. 11 – Approximation errors odometers neural network.**

This is because the prediction of the random component is difficult and requires an analysis of each situation. In represented results the neural network successfully predicted a systematic component.

## 8. CONCLUSIONS AND FUTURE WORK

The research characteristics were obtained for the specific mechanics of a real robot. Based on these characteristics, was realized calibration of control subsystems and positioning of the robot to solve the problem of localization. To clarify the position of the robot and increasing the quality and reliability of the information provided by the localization subsystem has been proposed neural network module. Experimental results proved the success of the approach. However, this approach has several disadvantages, such as the need to configure the neural network module for the particular robot and environment, the demand for performance avionics robot, necessity of an external video camera to measure the actual position of the robot. In the future for solving these problems is planned to create the intellectual positioning system that could adapt during the operation to the parameters of the robot, the environment and used to estimate the position other sensors of the robot.

## 9. ACKNOWLEDGMENTS

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