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AUTOMATIC SYSTEM OF LINEAR SPEED DETERMINATION

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Abstract—*The paper deals with building assessment system of linear speed. This system is based on the use of data from three-coordinate accelerometers and angular rate sensors. The calculation error for different source data. Use of the system proposed for mobile robots.*

Index terms—Linear speed, mobile robot.

I. Introduction

Currently, mobile vehicles are widely used in various areas of human activity. In particular, they are applied under hard external conditions: absence of roads, benchmarks, complication terrain. For solution of navigation problem it is necessary to determinate an accurate linear speed for mobile robots. The known electromechanical means of speed determination are odometers. But the use of odometer does not accurately determine the speed due to the complication terrain and the need to adhere to the curvilinear movement.

Currently, there are various approaches [1], [2] that are based on the use of accelerometers. But even the use of accelerometers does not provide the accurate speed determination. In this paper it is proposed a new approach based on the use of accelerometers and angular speed sensors. For this approach it is developed software which provides sufficient accuracy of estimation speed.

II. Problem Statement

The proposed system of speed determination has two two-coordinate sensors which can be installed sequentially (on the longitudinal axis of the vehicle), or in parallel in a transverse plane of the vehicle. Fig. 1 shows the measurement scheme of linear acceleration of the robot with a parallel arrangement of sensors.

Components of points *A* and *B* (control points, in which two accelerometers are set) acceleration are

$$a_A^k = \varepsilon l_{AO_2}; \qquad a_A^n = \omega^2 l_{AO_2};$$

$$a_B^k = \varepsilon l_{BO_2}; \qquad a_B^n = \omega^2 l_{AO_2},$$

where ε is the angular acceleration; ω is the angular velocity.

Components of points *A* and *B* acceleration in axis direction O_1X_1 and O_1Y_1 are determined as

$$a_{Ax_1} = a_A^k \cos a_A - a_A^n \sin a_A = l_{AO_2}\left(\varepsilon \cos a_A - \omega^2 \sin a_A\right);$$

$$a_{AY_1} = a_A^k \sin a_A + a_A^n \cos a_A = l_{AO_2}\left(\varepsilon \sin a_A + \omega^2 \cos a_A\right);$$

$$a_{Bx_1} = a_B^k \cos a_B - a_B^n \sin a_B = l_{BO_2}\left(\varepsilon \cos a_B - \omega^2 \sin a_B\right);$$

$$a_{Bx_1} = a_B^k \sin a_B + a_B^n \cos a_B = l_{BO_2}\left(\varepsilon \sin a_B + \omega^2 \cos a_B\right).$$

Mean values of linear acceleration components of control points in axis direction O_1X_1 and O_1Y_1 are determined as

$$\begin{aligned}\overline{a}_{X_1} &= \frac{1}{2}\left(a_{Ax_1} + a_{B_{x1}}\right)\\ &= \frac{1}{2}\varepsilon\left(l_{AO_2}\cos a_A + l_{BO_2}\cos a_B\right)\\ &-\frac{1}{2}\omega^2 (l_{BO_2}\sin a_B + l_{AO_2}\sin a_A) = \varepsilon R_D - \omega^2 l_{ED};\end{aligned} \tag{1}$$

$$\begin{aligned}\overline{a}_{Y_{11}} &= \frac{1}{2}\left(a_{AY_1} + a_{B_{Y1}}\right)\\ &= \frac{1}{2}\varepsilon\left(l_{AO_2}\sin a_A + l_{BO_2}\sin a_B\right)\\ &+\frac{1}{2}\omega^2\left(l_{AO_2}\cos a_A + l_{BO_2}\cos a_B\right) = \varepsilon l_{ED} - \omega^2 R_D.\end{aligned} \tag{2}$$

Differences of control points linear accelerations in the direction of axes are

$$\begin{aligned}a_{A_{Y1}} - a_{B_{Y1}} &= \varepsilon\left(l_{AO_2}\cos a_A + l_{BO_2}\cos a_B\right)\\ &-\omega^2\left(l_{AO_2}\sin a_A + l_{BO_2}\sin a_B\right) = \varepsilon l_{AB};\end{aligned} \tag{3}$$

$$\begin{aligned}a_{A_{X1}} - a_{B_{X1}} &= \varepsilon\left(l_{AO_2}\sin a_A + l_{BO_2}\sin a_B\right)\\ &+\omega^2\left(l_{AO_2}\cos a_A + l_{BO_2}\cos a_B\right) = \omega^2 l_{AB}.\end{aligned} \tag{4}$$

From equations (3) and (4) follows

$$\varepsilon = \frac{a_{AY_1} - a_{BY_1}}{l_{AB}}; \qquad \omega = \sqrt{\frac{a_{AX_1} - a_{BX_1}}{l_{AB}}}.$$

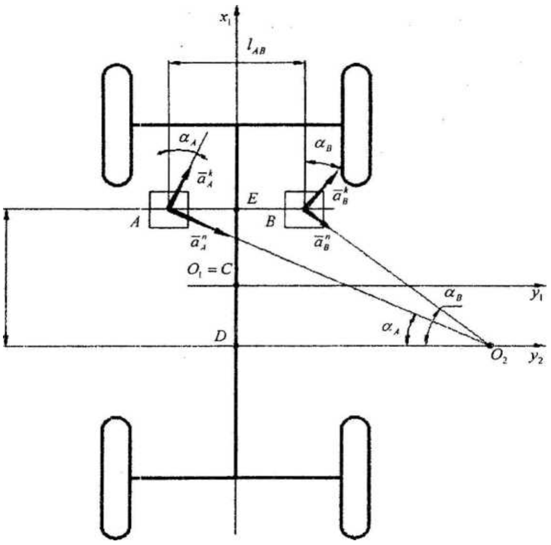

Fig. 1. Measurement scheme of mobile robot linear accelerations, installing two sensors in parallel in a transverse plane: *A* and *B* are sensor installation points; O_2 is the instantaneous center of rotation; *D* is the rotation pole

Equations (1) and (2) with known values of $\bar{a}_{X_1}, \bar{a}_{Y_1}, \varepsilon, \omega$ allow to determine the value l_{ED}, R_D. The values of R_D and l_{ED} are determined by the formulas

$$R_D = \frac{\bar{a}_{Y_1}\omega^2 - \bar{a}_{X_1}\varepsilon}{\varepsilon^2 - \omega^4}; \qquad l_{ED} = \frac{\bar{a}_{Y_1}\omega^2 + \bar{a}_{X_1}\varepsilon}{\varepsilon^2 + \omega^4}.$$

Thus, we have obtained the dependence of parameters determination l_{ED}, R_D, ε. These values can be determined in real time with help of onboard computer. Linear speed of the vehicle in the turning pole can be determined as [3].

$$V = \omega R_D.$$

III. Software Implementation of Mobile Robot Speed Measurement System

The main element of liner speed determination system is onboard computer which is realized by controller. For the transform of output signals from accelerometers into the values of speed in real scale of time it is necessary to use a separate microcontroller, which could be unloaded the main controller. As a result it has been designed the scheme of linear speed determination system (LSDS), as separate block as part of a mobile robot.

In linear speed determination system it is used the microcontroller Atmega2560, which receives signals from two three-axis accelerators (AC) 35203B of Summit Instruments company and adapters MAX487 for connection the bus RS-485 and UART (Universal Asynchronous Receiver-Transmitter) microcontroller. The block diagram of LSDS is shown in Fig. 2.

The information exchange between sensors and microcontroller is executed by two separate serial channels (Rx2, Tx2 and Rx3, Tx3) according to the standard RS-485. The result receiving is realized by serial communication channel RS-485 (Rx1, Tx1) in response to a request from the consumer. In the role of consumer is onboard computer or its separate unit that performs navigational calculations.

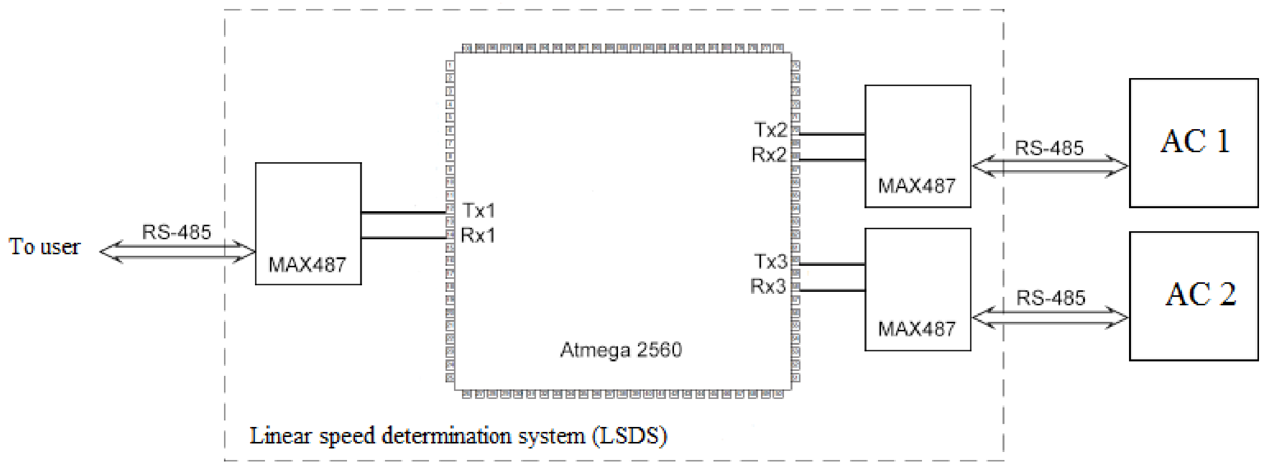

Fig. 2. Block diagram of speed sensor

Selected microcontroller has high characteristics for the timely receipt of measurement results, process and send the result in real scale of time mode. If it is necessary, possible to plug in an external clock generator to it to increase the clock frequency. Exchange rate for the interface RS-485 is 115.2 kbit/s, which is sufficient for operative reception of current value acceleration.

In the software of microcontroller it is used ready library functions to perform mathematical operations of computing speed. As noted above. microcontroller has enough memory and high speed for the use of ready library functions without manual optimization.

The functions for information exchange with sensors are typical for the work with UART microcontroller but they are tuned for the work with specific protocol of the sensors. Communication protocol by bus RS-485 of selected sensors assumes the transmission of measured acceleration value by each from three axes (channel 1, channel 2, channel 3) of 16 bits dimension. The detail description is representing by address: http://precisionsensors.meas-spec.com/faq.asp.

In Figure 3 it is showed a fragment of the computer program algorithm. After receiving the request from the consumer, the program sends a request to the sensors and expects current indications reception from both sensors. After reception is checked the checksum CRC16, which is sent with indications by sensor. If the data is correct, it is execute their conversion into physical values (the value of measured g by each channel) and speed calculation with using of above formulas. The main result is the value of instantaneous linear speed which is sent to the consumer.

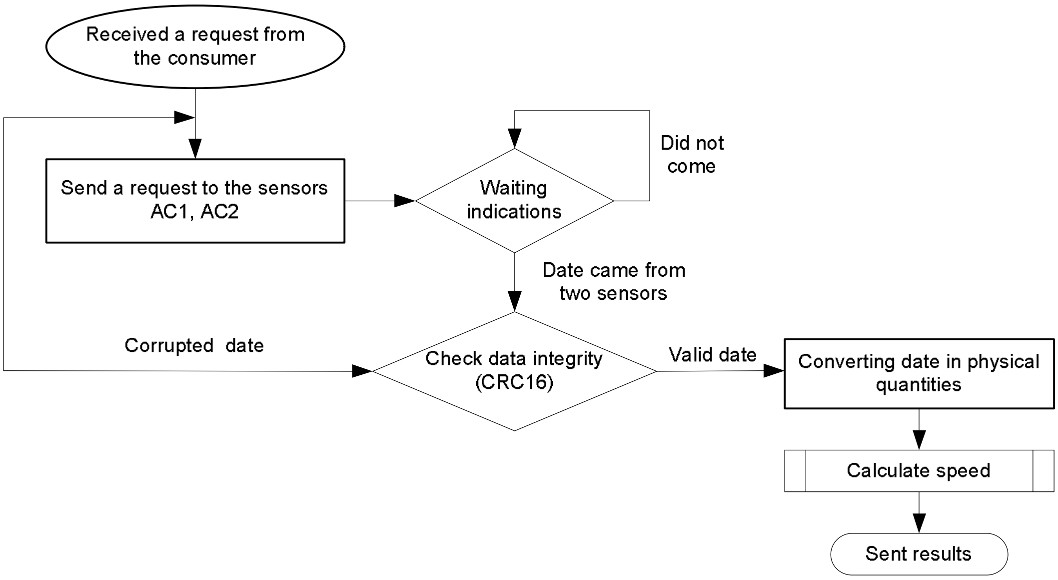

Fig. 3. The algorithm of the program (fragment)

The use of the represented block diagram (Fig. 2) of the linear speed determination system and selected accelerations with integrity data control CRC16 supplies small interval of time and high accuracy measurement speed.

IV. Error Measurement Determination of Kinematic Parameters of Mobile Robot

For determination of kinematic parameters measurement error of robot movement it's used the estimation error differential formulas

$$\varepsilon_u = \left|\frac{\partial U}{\partial x}\right|_{\substack{x=a\\y=b}} \cdot \varepsilon_a + \left|\frac{\partial U}{\partial y}\right|_{\substack{x=a\\y=b}} \cdot \varepsilon_b,$$

where ε_u, ε_a, ε_b are absolute errors of the function and arguments a and b; $\left|\frac{\partial U}{\partial x}\right|$, $\left|\frac{\partial U}{\partial y}\right|$ are modules of partial derivative function and the arguments a and b.

The angular acceleration error are determined as:

$$\varepsilon_\varepsilon = \left|\frac{a_{Ay} - a_{By}}{Y_{AB}^2 + X_{AB}^2} - 2X_{AB}\frac{Y_{AB}\left(a_{Ax_1} - a_{Bx_1}\right) + X_{AB}\left(a_{Ay_1} - a_{By_1}\right)}{\left(Y_{AB}^2 + X_{AB}^2\right)^2}\right|\varepsilon_{X_{AB}}$$
$$+\left|\frac{a_{Ax} - a_{Bx}}{Y_{AB}^2 + X_{AB}^2} - 2Y_{AB}\frac{Y_{AB}\left(a_{Ax_1} - a_{Bx_1}\right) + X_{AB}\left(a_{Ay_1} - a_{By_1}\right)}{\left(Y_{AB}^2 + X_{AB}^2\right)^2}\right|\varepsilon_{Y_{AB}} \quad (5)$$
$$+\left|\frac{Y_{AB}}{Y_{AB}^2 + X_{AB}^2}\right|\varepsilon_{a_{AX}} + \left|\frac{-Y_{AB}}{Y_{AB}^2 + X_{AB}^2}\right|\varepsilon_{a_{BX}} + \left|\frac{X_{AB}}{Y_{AB}^2 + X_{AB}^2}\right|\varepsilon_{a_{AY}} + \left|\frac{-X_{AB}}{Y_{AB}^2 + X_{AB}^2}\right|\varepsilon_{a_{AY}},$$

where $\varepsilon_{X_{AB}}$, $\varepsilon_{Y_{AB}}$ absolute errors of determining the coordinates of the location sensors:

$$\varepsilon_{X_{AB}} = \varepsilon_{Y_{AB}} = \varepsilon_1, \quad (6)$$

$\varepsilon_{a_{AX}}, \varepsilon_{a_{BX}}, \varepsilon_{a_{AY}}, \varepsilon_{a_{BY}}$ are the absolute errors of accelerations determination according to the coordinates

$$\varepsilon_{a_{AX}} = \varepsilon_{a_{BX}} = \varepsilon_{a_{AY}} = \varepsilon_{a_{BY}} = \varepsilon_a, \quad (7)$$

Equation (5) with considering (6), (7) can be represented as:

$$\varepsilon_\varepsilon = \varepsilon_1 \left(\left| \frac{a_{Ay_1} - a_{By_1}}{Y_{AB}^2 + X_{AB}^2} - 2\varepsilon \frac{X_{AB}}{Y_{AB}^2 + X_{AB}^2} \right| + \left| \frac{a_{Ax_1} - a_{Bx_1}}{Y_{AB}^2 + X_{AB}^2} - 2\varepsilon \frac{Y_{AB}}{Y_{AB}^2 + X_{AB}^2} \right| \right) + 2\varepsilon_a \frac{X_{AB} + Y_{AB}}{Y_{AB}^2 + X_{AB}^2}.$$

The error of the angular velocity determination with considering (6), (7) can represent as

$$\varepsilon_\varepsilon = \frac{1}{2\omega} \left(\left| \frac{a_{Ay_1} - a_{By_1}}{Y_{AB}^2 + X_{AB}^2} - 2\varepsilon \frac{X_{AB}}{Y_{AB}^2 + X_{AB}^2} \right| + \left| \frac{a_{Ax_1} - a_{Bx_1}}{Y_{AB}^2 + X_{AB}^2} - 2\varepsilon \frac{Y_{AB}}{Y_{AB}^2 + X_{AB}^2} \right| \right) + 2\varepsilon_a \frac{X_{AB} + Y_{AB}}{Y_{AB}^2 + X_{AB}^2}.$$

The error of coordinates determination of elasticity center of a robot with considering (6), (7) can represent as:

$$\varepsilon_{XA} = \left| \frac{a_{x_1} - 2\varepsilon\left(X_A + 0.5X_{AB}\right)}{\varepsilon^2 + \omega^4} \right| \varepsilon_\varepsilon + \left| \frac{-2\omega a_{x1} - 4\omega^3\left(X_A + 0.5X_{AB}\right)}{\varepsilon^2 + \omega^4} \right| \varepsilon_\omega + \frac{\varepsilon + \omega^2}{\varepsilon^2 + \omega^4} \varepsilon_a + 0.5\varepsilon_1.$$

The error instantaneous turning radius determination of a robot is based on formulas (6), (7)

$$\varepsilon_{R_D} = \left| \frac{a_{x1} - 2\varepsilon\left(R_D + 0.5\left(Y_A - Y_B\right)\right)}{\varepsilon^2 + \omega^4} \right| \varepsilon_\varepsilon + \left| \frac{2\omega a_{y1} - 4\omega^3\left(R_D + 0.5\left(Y_A - Y_B\right)\right)}{\varepsilon^2 + \omega^4} \right| \varepsilon_\omega + \frac{\varepsilon + \omega^2}{\varepsilon^2 + \omega^4} \varepsilon_a + 0.5\varepsilon_1.$$

The error of a mobile robot speed determination can represent as [3]:

$$\varepsilon_{V_D} = \left|R_D\right| \varepsilon_\omega + \left|\omega\right| \varepsilon_{R_D}.$$

The relative errors speed determination by accelerometer's method is represented in Table I.

TABLE I

THE RELATIVE ERRORS SPEED DETERMINATION BY ACCELEROMETER'S METHOD

R_D \ V_D	3	5	7	10	15	20
5	2.93	2.62	2.33	2.12	2.00	1.96
10	2.75	2.50	2.40	2.35	2.32	2.31
25	5.22	3.33	3.06	2.76	2.28	2.03
50	15.76	6.72	4.41	3.41	3.05	2.75
75	33.34	13.03	7.48	4.67	3.43	3.15
100	58.19	21.94	11.97	6.77	4.17	3.44

The relative errors of determining speed with help sensor of angular velocity and accelerometers is represented in Table II.

TABLE 2

THE RELATIVE ERRORS OF DETERMINING SPEED WITH HELP SENSOR OF ANGULAR VELOCITY AND ACCELEROMETERS

R_D \ V_D	3	5	7	10	15	20
5	1.42	1.16	1.08	1.04	1.02	1.01
10	1.43	1.02	0.78	0.63	0.56	0.53
25	1.15	1.29	1.25	0.93	0.55	0.39
50	1.05	1.11	1.18	1.25	1.13	0.83
75	1.03	1.06	1.09	1.16	1.24	1.19
100	1.02	1.04	1.06	1.10	1.18	1.23

V. CONCLUSIONS

The methods analysis of linear speed determination has been done. It is shown that the most perspective method is a combined method of the speed determination through the use of accelerators and angular velocity sensor.

It has been done an algorithm of speed determination by use of accelerometer's method. The analysis of system errors speed determination depending on the speed, radius, sensors' accuracies is represented. It is shown that the system which is built in accelerometers and sensor of angular speed, gives best results.

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В. М. Синєглазов, Є. В. Даскал, О. А. Петриченко. Автоматична система визначення лінійної швидкості

Розглянуто побудову системи оцінювання лінійної швидкості. Систему побудовано на основі використання даних з триступеневих акселерометрів та датчиків кутової швидкості. Проведено розрахунок похибок для різних вихідних даних. Запропоновано використання даної системи для мобільних роботів.

Ключові слова: лінійна швидкість, мобільний робот.

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В. М. Синеглазов, Є. В. Даскал, О. А. Петриченко. Автоматическая система опредиления линейной скорости

Рассмотрено построение системы оценивания линейной скорости. Система построена на основе использования данных с трехступенчатых акселерометров и датчиков угловой скорости. Проведен расчет погрешностей для различных исходных данных. Предложено использование данной системы для мобильных роботов.

Ключевые слова: линейная скорость, мобильний робот.

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