Positioning and Navigation Motion Control System for Wheeled Mobile Robot

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Abstract

Being able to navigate accurately is one of the fundamental capabilities of a mobile robot to effectively execute a variety of tasks including docking, transportation, and manipulation. To achieve the desired navigation accuracy, mobile robots are typically equipped with on-board sensors to observe persistent features in the environment, to estimate their pose from these observations, and to adjust their motion accordingly. Odometry is the most widely used navigation method for mobile robot positioning because it provides good short-term accuracy, is inexpensive, and allows very high sampling rates. This paper presents experimental results of a new method for detecting and correcting odometry errors. The fundamental idea of odometry is the integration of incremental motion information over time, which leads inevitably to the accumulation of errors. Particularly, the accumulation of orientation errors will cause large position errors [1], which increase proportionally with the distance travelled by the robot. The errors arising during robot working were discussed and suggestions to correct these errors were presented.

I. INTRODUCTION

Navigation is a field of study that focuses on the process of monitoring and controlling the movement of a craft or vehicle from one place to another [2]. The field of navigation includes four general categories: land navigation, marine navigation, aeronautic navigation, and space navigation [3]. It is also the term of art used for the specialized knowledge used by navigators to perform navigation tasks. All navigational techniques involve locating the navigator's position compared to known locations or patterns.

Navigation, in a broader sense, can refer to any skill or study that involves the determination of position and direction. In this sense, navigation includes orienteering and pedestrian navigation [3]. For any mobile device, the ability to navigate in its environment is important. Avoiding dangerous situations such as collisions and unsafe conditions (temperature, radiation, exposure to weather, etc.) comes first, but if the robot has a purpose that relates to specific places in the robot environment, it must find those places.

Robot navigation means the robot's ability to determine its own position in its frame of reference and then to plan a path towards some goal location. In order to navigate in its environment, the robot or any other mobility device requires representation, i.e. a map of the environment and the ability to interpret that representation. Navigation can be defined as the combination of the three fundamental competences:

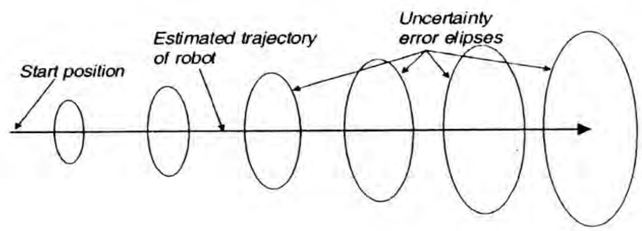
- Self-localization (Positioning)
- Path planning
- Map-building and map interpretation

Robot localization (Positioning) denotes the robot's ability to establish its own position and orientation within the frame of reference. Path planning is effectively an extension of localization, in that it requires the determination of the robot's current position and a position of a goal location, both within the same frame of reference or coordinates. Map building can be in the shape of a metric map or any notation describing locations in the robot frame of reference.

The positioning system is the most essential component. The role of positioning system is to answer the question “Where am I? The answer can be a relative or absolute position to the robot. Nowadays, Mobile robots have variety of tasks. There are not only a few of them exploring foreign planets, but mobile robots are widely used for performing repetitive tasks in different industries. These different applications of mobile robots all have in common that the quality with which the robot can autonomously full its task depends strongly on the localization accuracy of the robot [4].

In order to accurately localize themselves, mobile robots are typically equipped with on-board sensors, like cameras or laser range, to observe their environment or combined with another method of navigation in order to eliminate errors in positioning. One of the major tasks of autonomous robotics navigation is localization. In a typical indoor environment with a flat floor plan, localization becomes a matter of determining the Cartesian coordinates (x,y) and the orientation θ, collectively known as the state, of the robot on a two dimensional floor plan. For a typical two wheel robot, odometry (also known as dead-reckoning) remains to be one of the most important means of achieving this task.

Fig.1. Growing "error ellipses" indicate the growing position uncertainty with odometry.



In this paper, the odometry navigation system used in a mobile robot system is described and discussed. Section 2, presents the robot positioning system using odometry and the errors that can affect the accuracy of the positioning of the robot, section 3 describes the remote control mobile robot system, section 4 shows the wheeled mobile robot design , section 5 presents robot positioning calculations and the encoder used, section 6 gives the conclusions extracted from the work.

II. ODOMETRY

Odometry is the most widely used navigation method for mobile robot positioning because it provides good short-term accuracy, is inexpensive, and allows very high sampling rates. However, the fundamental idea of odometry is the integration of incremental motion information over time, which leads inevitably to the accumulation of errors. Particularly, the accumulation of orientation errors will cause large position errors [1], which increase proportionally with the distance travelled by the robot. Nonetheless, most researchers agree that odometry is an important part of a robot navigation system and that navigation tasks will be simplified if odometric accuracy can be improved.

Odometry is the measurement of wheel rotation as a function of time. If the two wheels of the robot are joined to a common axle, the position and orientation of the centre of the axle relative to the previous position and orientation can be determined from odometry measurements on both wheels. In practice, optical encoders that are mounted onto both drive wheels feed discretised wheel increment information to the central processor, which in turn continually updates the robot's state using geometric equations. However, with time, odometric localization accumulates errors in an unbounded fashion due to wheel slippage, floor roughness and discretised sampling of wheel increments. A lot of research works have been undergone at both the hardware and theoretical level to improve the reliability of odometry. When trying to measure and reduce odometry errors, it is important to understand the distinction between systematic and non-systematic odometry errors.

Systematic errors are those errors that are inherently part of the robot's kinematic or controller properties, independently from the robot's environment.

Non-systematic errors are those that depend on the robot's environment and differ from one environment to another. This distinction is important because each one of these two groups affects mobile platforms differently, their remediation differs, and, most important, both groups require different measuring techniques in order to obtain meaningful and comparable experimental data.

We categorize odometry errors as follows:

A. Systematic errors

- Unequal wheel diameters
- Average of both wheel diameters differs from nominal diameter
- Misalignment of wheels
- Uncertainty about the effective wheelbase (due to non-point wheel contact with the floor)
- Limited encoder resolution
- Limited encoder sampling rate

B. Non-systematic errors

- Travel over uneven floors
- Travel over unexpected objects on the floor
- Wheel-slippage (slippery floors, over-acceleration, skidding in fast turns, etc.)
- External forces (interaction with external bodies)
- Internal forces (e.g., castor wheels)
- Non-point wheel contact with the floor

Some research has examined the use of inertial navigation aids. However, experimental results from [5] and [6], indicate that a purely inertial navigation approach is not realistically advantageous (i.e., too expensive or too inaccurate) for mobile robot applications.

It is noteworthy that many researchers develop algorithms that estimate the position uncertainty of a dead-reckoning robot [7], [8]**.** With this approach each computed robot position is surrounded by a characteristic "error ellipse", which indicates a region of uncertainty for the robot's actual position, Fig. 1 [7], [9]**.** Typically, these ellipses grow with travel distance, until an absolute position measurement reduces the growing uncertainty and thereby "resets" the size of the error ellipse which called Position Estimation Error (PEE).

These error estimation techniques must rely on error estimation parameters derived from observations of the vehicle's dead-reckoning performance. Clearly, these parameters can take into account only systematic errors, because the magnitude of non-systematic errors is unpredictable [10], [11]**.**

III. REMOTE CONTROL MOBILE ROBOT

Modern robotics occurred in the 60-70th of the last century as a response to the overall automation of requests when the resulting compound manned manipulators systems of numerical control machine tools and other technological equipment were automatic machines of a new type. They were robots with programmed control - the first generation of robots.

The success of the first robots has caused the rapid growth of demand for them, and therefore the requirement s for their abilities. They began to develop robots with combined control, in which the control software is complemented by the management of the human operator - robots intermediate one and a half generation supervisory, and then the interactive controls. In those years, the first steps began to make the theory of adaptive management. And one of the first machines with this control becomes adaptive robots. This second-generation robots, equipped with sensory.

With the development of adaptive control systems have been used in these methods of artificial intelligence. When these technologies are taken determines the position in the algorithmic maintenance management systems, formed a new third-generation robots - intelligent robots.

Conventionally, all mobile robot remote control methods can be divided into the following groups:

- Automation level (manual, semi-automatic, automatic transmission)
- Data transmission and processing method (wired, wireless (Wi-Fi), the combination)
- Navigation method (GPS, GSM, cameras, gyroscopes, accelerometers, sonar).

A. Mobile Robot Control Modes

At present, almost all unmanned (terrestrial, aerial, underwater) mobile systems have three control modes:

- Manual (all the functions are carried out by the operator of the mobile complex)
- Semi-automatic (part of the functions performed apparatus of the operator)
- Automatic (all functions are performed by the device).

1) Manual Mode: In this mode, remote manual control changes the direction of movement of the robot, which is often all, is one or two joysticks connected to the computer. The operator, sitting in the mobile control station in front of a computer screen, can "see" what is in front and to the side, and also determine the distance to objects, the depth of the ditches and the slope of the surface, using located on the mobile robot cameras, laser rangefinders, machine inclination sensors and other sensors is controlled via the radio or wire.

2) Semi-automatic Mode: In the semi-automatic, robot controller can automatically move to the object, and for the control takes the operator, or on the contrary, the operator responsible for the movement of the robot to the object and then puts the robot in automatic mode. Also, when operating in automatic mode and the situation occurs robot can send a signal to the control panel that the operator must be involved.

3) Automatic Mode: The greatest importance will certainly have modern methods of automatic control. The most typical of the mobile robot are management techniques, based on:

- Biological Principles
- Inductive method of self-organization models
- Robust control
- Discrete Time Model
- Fuzzy models

IV. WHEELED MOBILE ROBOT DESIGN

The wheel has been by far the most popular locomotion mechanism in mobile robotics and in man-made vehicles in general. It can achieve very good efficiencies, and it does so with a relatively simple mechanical implementation. In addition, balance is not usually a research problem in wheeled robot designs, because wheeled robots are almost always designed so that all wheels are in ground contact at all times. Thus, three wheels are sufficient to guarantee stable balance, although, two-wheeled robots can also be stable. When more than three wheels are used, a suspension system is required to allow all wheels to maintain ground contact when the robot encounters uneven terrain.

Instead of worrying about balance, wheeled robot research tends to focus on the problems of traction and stability, maneuverability, and control: can the robot wheels provide sufficient traction and stability for the robot to cover all of the desired terrain, and does the robot's wheeled configuration enable sufficient control over the velocity of the robot?

A. Design of Belarus-132N mobile robot

The Mobile robot used in the experiment use chassis tractors "Belarus-132N" platform with the petrol engine (HONDA GX390) [12]. The power and traction, originally designed for plowing the soil, it is sufficient to ensure that the movement of the trolley up to 500 kg, or clearing blockages with regular attachments. Articulated frame chassis tractors "Belarus-132N" provides exceptional manoeuvrability of the robot with the smallest turning radius - 2,5 meters, which can be a key factor in the application of complex in a congested urban traffic streets, in the woods, tunnels and even in large rooms. Its weight is about 400 kg with dimensions of 120×120×180 cm3. Physical Specifications allow transporting it in the cargo van with a medium wheelbase or a conventional single-axle trailer. General view of the current mobile robot system is shown in Fig. 2.

The Mobile Robot System, in addition to the serial chassis, includes the following systems and components: a video system for driving; mechatronic motion control system; on-board computer; telecommunication systems with a remote control unit; staff attachments, such as blade; special attachments, such as arm, master stream nozzle for fire-fighting as shown in Fig.2. The mobile robot will move "backward-to-front" during this movement the robotic system will be in a secure area, and will not interfere with the video system and the special attachments.

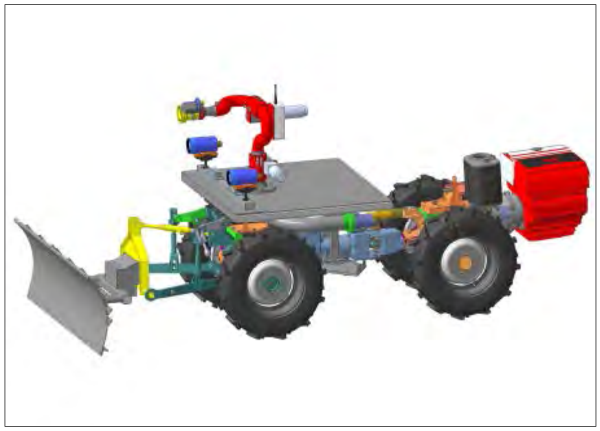


Fig.2. General View of the Belarus 132N Robotic System [12]

B. Mobile Robot Configuration

The accuracy of odometry measurements for dead reckoning is to a great extent a direct function of the kinematic design of a vehicle. Because of this close relation between kinematic designs and positioning accuracy, one must consider the kinematic design closely before attempting to improve dead-reckoning accuracy.

The robot can perform dead reckoning by using simple geometric equations to compute the momentary position of the vehicle relative to a known starting position.

Mobile Robot Belarus-132N is designed (as in *Ackerman Steering*) to ensure that the inside front wheel is rotated to a slightly sharper angle than the outside wheel when turning, thereby eliminating geometrically induced tire slippage.

As shown in Fig. 3, the extended axes for the two front wheels intersect in a common point that lies on the extended axis of the rear axle. The locus of points traced along the ground by the centre of each tire is thus a set of concentric arcs about this centre-point of rotation P_1 ,and (ignoring for the moment any centrifugal accelerations) all instantaneous velocity vectors will subsequently be tangential to these arcs. Such a steering geometry [13] is said to satisfy the Ackerman equation:

$$\cot\theta_i + \cot\theta_o = \frac{d}{l} \qquad (1)$$

Where

θ_i = relative steering angle of the inner wheel

θ_o= relative steering angle of the outer wheel

l = longitudinal wheel separation

d = lateral wheel separation.

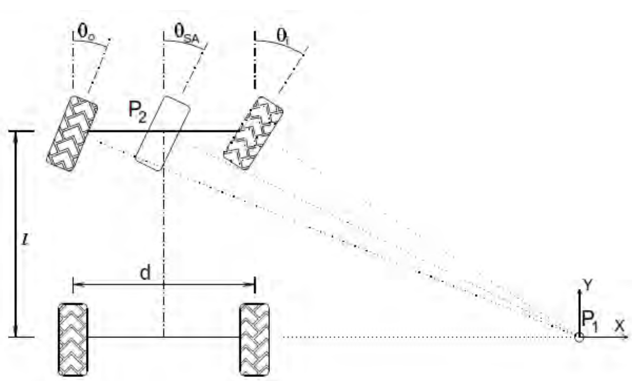


Fig.3. In an Ackerman-steered vehicle, the extended axes for all wheels intersect in a common point

The vehicle steering angle θ_{SA} can be thought of as the angle (relative to vehicle heading) associated with an imaginary centre wheel located at a reference point P_2 as shown in the figure above. θ_{SA} can be expressed in terms of either the inside or outside steering angles (θ_i or θ_o) as follows:

$$\cot\theta_{SA} = \frac{d}{2l} + \cot\theta_i \tag{2}$$

Or

$$\cot\theta_{SA} = \cot\theta_o - \frac{d}{2l} \tag{3}$$

***C.** Discrete Time Model of Belarus-132N Wheeled Mobile Robot*

The robot is assumed to be moved in a flat plane where the motion *P* can be described in I_{xp} and I_{yp} direction using four wheels. The direction θ determines the rotation of mobile robot in counter clockwise. The robot motion can be described in two coordinate systems: global coordinate system I_x , I_y axis and Local coordinate system E_x , E_y as in Fig. 4.

1) Local Coordinates and Transformations: In the global coordin1ate system, the motion can be obtained in three axes q= [x, y, θ]^T, whereas the local coordinate system has only two axes E_x , E_y. The rotation matrix describes the transformation of a point in the global frame called I_x to the local frame E_x is shown in Fig.4.

The transformation from the local frame to the global frame is done using the inverse $R(\theta)^{-1}$.

So that $R(\theta)^{-1} = R(\theta)$

$$\mathbf{R}(\theta) = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$$\mathbf{R}(\theta)^{\mathrm{T}} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{5}$$

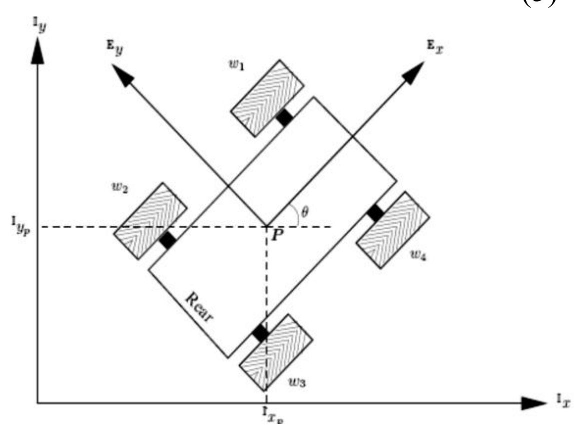


Fig.4. Location of Wheeled Mobile Robot with respect to global and local coordinate system

The four wheels position of the robot w_1 to w_4 are interconnected two by two and rotate by the angles γ_1 to γ_4.

$$\gamma_1 = \gamma_4 \quad \text{and} \quad \gamma_2 = \gamma_3 \tag{6}$$

2) New Position P' of Motion Model: If a robot starts from a position p, and the right and left wheels move respective distances L_k and R_k. Then the new position of $\mathbf{p}'$ will be calculated.

Assume that the robot is travelling on a circular arc of constant radius as shown in Fig. 5 and the change in angle α and distance travelled Δs (the line joining the point p and p').

Begin by noting the following holds for circular arcs:

$$L_k = r_k\alpha \quad (7)$$
$$R_k = (r_k + 2L)\alpha \quad (8)$$
$$\Delta s = (r_k + L)\alpha \quad (9)$$

By manipulating the equations (7) and (8):

$$L_k = r_k\alpha \quad (7)$$
$$R_k = (r_k + 2L)\alpha \quad (8)$$

To:

$$L_k = r_k\alpha \quad (7)$$
$$L\alpha = \frac{(R_k - r_k\alpha)}{2} \quad (11)$$
$$L\alpha = \frac{R_k}{2} - \frac{L_k}{2} \quad (12)$$

Substitute eq. (10) and (12) into (9):

$$\Delta s = (r_k + L)\alpha \quad = r_k\alpha + L\alpha$$
$$\Delta s = L_k + \frac{R_k}{2} - \frac{L_k}{2} = \frac{L_k}{2} + \frac{R_k}{2}$$
$$\Delta s = \frac{L_k + R_K}{2} \quad (13)$$

So that the distance the centre (p) travelled is simply the average distance of each wheel:

$$\Delta s = \frac{L_k + R_K}{2}$$

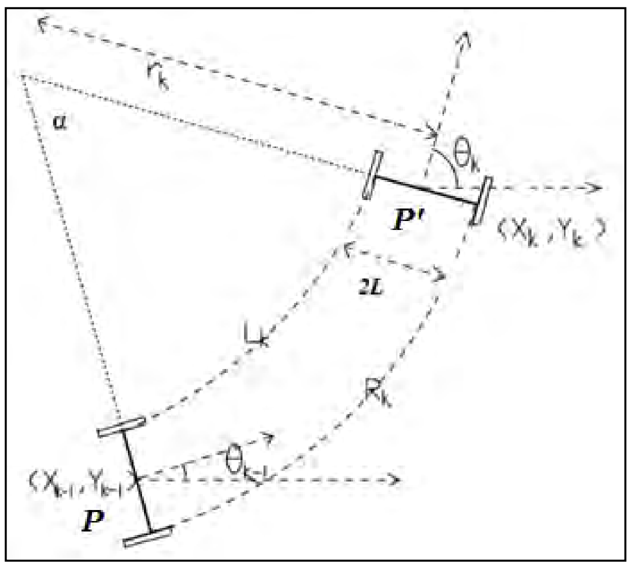


Fig.5. Motion model of Wheeled Mobile Robot on a circular arc of constant radius

3) Position change in the global coordinates: To calculate the change in angle θ_k , observe that it equals the rotation about the circular arc's center point.

$$\theta_k = \alpha \quad (14)$$

So we solve for α by equating α from the two equations (7) and (8), this results in:

$$\frac{L_k}{r_k} = \frac{R_k}{r_k + 2L} \quad (15)$$

After expand and simplify the eq. (15):

$$r_k = \frac{2L\,L_k}{R_k - L_k} \quad (16)$$

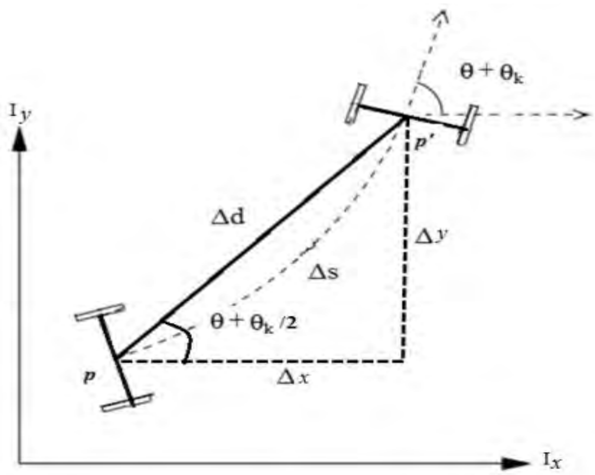


Fig.6. Global coordinates of Wheeled Mobile Robot

Substitute eq. (15) into eq. (7) to calculate α.

$$\alpha = \frac{L_k}{r_k} \qquad (17)$$

$$\alpha = \frac{R_k - L_k}{2L} \qquad (18)$$

So

$$\theta_k = \frac{R_k - L_k}{2L} \qquad (19)$$

In order to calculate the position change in global coordinates using Fig.6. We use θ_k , Δs, and length Δd.
Using Trig:

$$\Delta x = \Delta d \cos(\theta + \theta_k/2) \qquad (20)$$
$$\Delta y = \Delta d \sin(\theta + \theta_k /2) \qquad (21)$$

Where Δd is the change in position
Assume that the motion is small, and then we can assume that Δd ≈ ΔS, so eq. (20) and (21) will be:

$$\Delta x = \Delta S \cos(\theta + \theta_k/2) \qquad (22)$$
$$\Delta y = \Delta S \sin(\theta + \theta_k /2) \qquad (23)$$

So the new position of Mobile Robot *p'* is:

$$P' = f(x, y, \theta, R_k, L_k) = p + \begin{bmatrix} \Delta x \\ \Delta y \\ \Delta\theta \end{bmatrix} \quad \text{and} \quad p = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix}$$

$$P' = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix} + \begin{bmatrix} \frac{R_k + L_k}{2} \cos(\theta + \frac{R_k - L_k}{2L}) \\ \frac{R_k + L_k}{2} \sin(\theta + \frac{R_k - L_k}{2L}) \\ \frac{R_k - L_k}{L} \end{bmatrix} \qquad (24)$$

D. *Kinematic model of mobile robot*

The continuous-time kinematic model [14] of a mobile robot at point $p(x_p , y_p , \theta_p)$ as shown in Fig. 7 is given by:

$$\dot{x_p} = V\cos\theta \qquad \dot{y_p} = V\sin\theta \qquad \dot{\theta_p} = \omega_p \qquad (25)$$
$$V = -\frac{K(V_1 + V_2)}{2} \qquad \omega = -\frac{K(V_1 - V_2)}{2} \qquad (26)$$

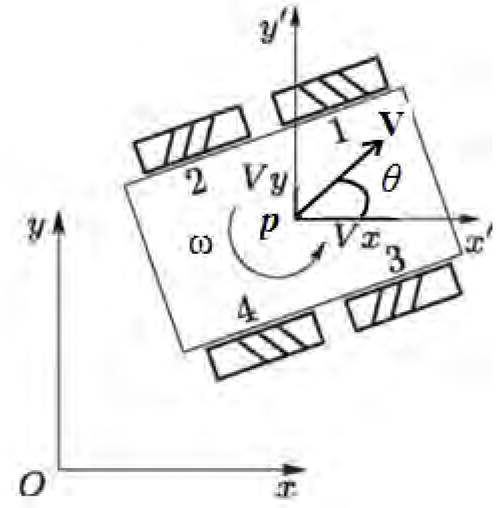


Fig.7. Kinematic Position of a Wheeled Mobile Robot

Where x and y represent the coordinates of the centre of the axis of the actuated wheels on the plane X-Y and θ is the angle formed by the longitudinal axis of the robot and the X axis. V represents the linear velocity, ω represents the angular velocity, V1 and V2 - longitudinal velocity of the wheel while K - drive transmission ratio. The kinematic model of a four wheeled mobile robot is shown in Fig. 8.

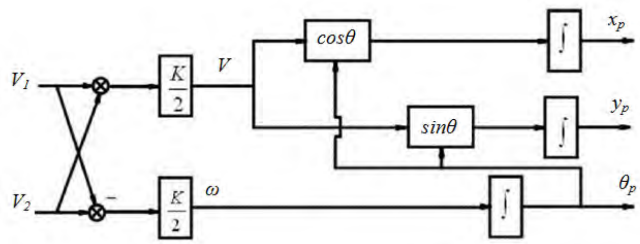


Fig.8. Kinematic Model of a Wheeled Mobile Robot

Considering an example break Ts and a zero-appeal hold, eq. (25) movements in discrete-time to:

$$\begin{cases} x_p[k+1] = x_p[k] + V[k].cos\theta[k].T_s \\ y_p[k+1] = y_p[k] + V[k].sin\theta[k].T_s \\ \theta_p[k+1] = \theta_p[k] + \omega[k].T_s \end{cases} \quad (27)$$

Consequently a virtual robot, with the looked for heading $q_d(t)=[\ x_d(t)\ y_d(t)\ \ \theta_d(t)\ ]$ is viewed as coming about the accompanying kinematic model, Mathematical statement of the virtual robot can be communicated as:

$$\dot{x_d} = V_d cos\theta_d \qquad \dot{y_d} = V_d sin\theta_d \qquad \dot{\theta_d} = \omega_d \qquad (28)$$

Where $p_d=(x_d\ ,\ y_d\ ,\ \theta_d)$ represents the desired pose, V_d the desired linear speed, w_d the desired angular. Considering an example break Ts and a zero-appeal hold, eq. (28) movements in discrete-time to:

$$\begin{cases} x_d[k+1] = x_d[k] + V_d[k].cos\theta_d[k].T_s \\ y_d[k+1] = y_d[k] + V_d[k].sin\theta_d[k].T_s \\ \theta_d[k+1] = \theta_d[k] + \omega_d[k].T_s \end{cases} \quad (29)$$

The errors (mistake) between the real robot and desired (virtual) robot are demonstrated as follows:

$$\begin{bmatrix} x_e \\ y_e \\ \theta_e \end{bmatrix} = \begin{bmatrix} cos\theta_d & sin\theta_d & 0 \\ -sin\theta_d & cos\theta_d & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_p - x_d \\ y_p - y_d \\ w_p - w_d \end{bmatrix} \qquad (30)$$

Considering an example break Ts and a zero-appeal hold, eqn. (30) in discrete-time to:

$$\begin{cases} x_e[k] = x_{pd}[k].cos\theta_e[k] + y_{pd}[k].sin\theta_e[k] \\ y_e[k] = -x_{pd}[k].sin\theta_e[k] + y_{pd}[k].cos\theta_e[k] \\ \theta_e[k] = \theta_p[k] - \theta_d[k] \end{cases} \quad (31)$$

$$x_{pd}[k] = x_p[k] - x_d[k] \quad (32)$$

$$y_{pd}[k] = y_p[k] - y_d[k] \quad (33)$$

The error dynamics for direction following are characterized as:

$$\dot{x_e} = -V_d + V_p cos\theta_e + \omega_d y_e$$

$$\dot{y_e} = V_p sin\theta_e - \omega_d x_e$$

$$\dot{\theta_e} = \theta_p - \theta_d$$

V. ROBOT POSITIONING CALCULATION

There are many methods for robot positioning that can roughly be categorized into two groups: relative and absolute position measurements. Odometry is one of the relative position measurement methods. This method uses encoders to measure wheel rotation and/or steering orientation.

A. Rotational Displacement Equipment

There are different types of rotational displacement and velocity sensors in use today:

1. Brush encoders
2. Potentiometers
3. Resolvers.
4. Optical encoders.
5. Magnetic encoders
6. Inductive encoders
7. Capacitive encoders

For mobile robot applications incremental optical encoders are the most popular type.

B. Incremental Optical Encoders

An encoder is an electrical mechanical device that converts linear or rotary displacement into digital or pulse signals. The most popular type of encoder is the optical encoder, which consists of a rotating disk, a light source, and a photo detector (light sensor). The disk, which is mounted on the rotating shaft, has patterns of opaque and transparent sectors coded into the disk (see Fig. 9). As the disk rotates, these patterns interrupt the light emitted onto the photo detector, generating a digital or pulse signal output.

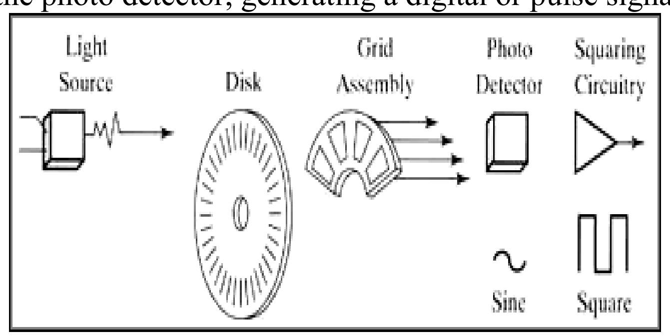


Fig.9. Rotary Incremental Optical Encoder

An incremental encoder generates a pulse for each incremental step in its rotation. Although the incremental encoder does not output absolute position, it can provide high resolution at an acceptable price. For example, an incremental encoder with a single code track, referred to as a tachometer encoder, generates a pulse signal whose frequency indicates the velocity of displacement. However, the output of the single-channel encoder does not indicate direction. To determine direction, a two-channel, or quadrature, encoder uses two detectors and two code tracks [15].

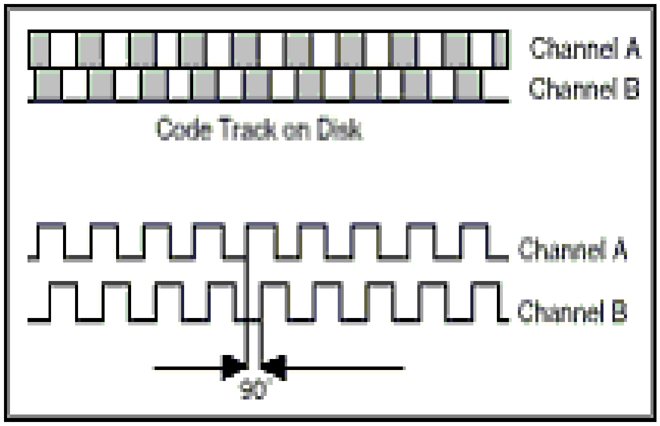


Fig.10. Examples of the A pulse and B pulse. If the A pulse occurs before the B pulse, the shaft is turning clockwise, and if the B pulse occurs before the A pulse, the shaft is turning counter-clockwise.

The most common type of incremental encoder uses two output channels (A and B) to sense position as shown in Fig.10. Using two code tracks with sectors positioned 90° out of phase; the two output channels of the quadrature encoder indicate both position and direction of rotation. If A leads B, for example, the disk is rotating in a clockwise direction. If B leads A, then the disk is rotating in a counter-clockwise direction. Therefore, by monitoring both the number of pulses and the relative phase of signals A and B, you can track both the position and direction of rotation.

In addition, some quadrature detectors include a third output channel, called a zero or reference signal, which supplies a single pulse per revolution. This single pulse can be used for precise determination of a reference position.

CONCLUSION

In this paper, the motion control system and algorithm for a Belarus-132N Mobile Robot was presented. The robot positioning was calculated using odometry method. The distance travelled by the robot was calculated by transforming the number of the wheels revolutions counted using an incremental optical encoder to a linear distance knowing the diameter of the wheel. It is known that odometry suffers from a number of errors that result on inaccurate distance calculations.

The errors of odometry method are systematic and non-systematic. During testing the robot system navigation (positioning) using odometry errors was measured. Odometry, used to estimate the position of a mobile robot, employs encoders attached to the robot's wheels. However, errors occur caused by the integrative nature of the rotating speed and the slippage between the wheel and the ground.

To overcome this issue, we must use odometry with another inertial system or external-reference sensors. For example, inertial navigation systems (INS) are composed of inertial sensors, such as accelerometers and gyroscopes. An INS updates its orientation and position automatically.

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