Mirosław ŚMIESZEK, Magdalena DOBRZAŃSKA, Paweł DOBRZAŃSKI
RZESZOW UNIVERSITY OF TECHNOLOGY
10 Powstańców Warszawy Ave., 35-959 Rzeszów

Laser navigation applications for automated guided vehicles

Abstract

In this paper, the basics of navigation in automated guided vehicles are presented. Errors in determining the position and methods used for the position correction are described. These methods are based on laser technology. In the work, two such methods are presented. The first one uses a laser scanner to measure the angles between the markers. The second method uses a laser scanner applied to the development of digital maps. The considerations included in the work are supported by some examples.

Keywords: navigation, automated guided vehicles, laser scanners.

1. Introduction

Automated Guided Vehicles (AGV) are commonly used in various areas of man's activities. Over the last two decades, there has been a rapid development of automated guided vehicles which have their applications in totally different areas, e.g. medicine, industry, transport, defense or agriculture. Odometry, an analytical navigation, is the base for positioning in automated guided vehicles. Odometry consists in determining the vehicle current position on the basis of the way covered by a characteristic point K. To determine the vehicle movement direction angle θ, the analytical navigation uses the difference of speed of driving wheels v_L and v_P . The basic idea of this solution is shown in Fig. 1.

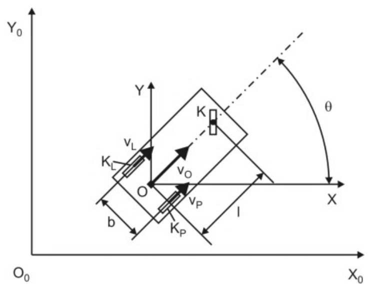

Fig. 1. Coordinate system used in analytical navigation

The applied method relies on measurement of the way covered by the driven wheels K_L and K_R and the determination the direction angle θ in each iteration of the vehicle movement. The method is used for the vehicles in which two drive wheels are independently driven to steer the vehicle. The proper differentiation of the rotational speed of these wheels forces a turn of the vehicle around its vertical axis of rotation which goes through the point O and the change in the direction angle θ [7, 10].

If the point position O of vehicle, in which two independently driven wheels K_L and K_P are used to steer the vehicle, in the basic reference system $X_0O_0Y_0$ (Fig. 1) in k^{th} iteration is given by the state vector $(x(k), y(k), \theta(k))$, then the position of the vehicle in $(k+1)^{th}$ iteration is given by the equation:

$$\begin{bmatrix} x(k+1) \\ y(k+1) \\ \theta(k+1) \end{bmatrix} = \begin{bmatrix} x(k) \\ y(k) \\ \theta(k) \end{bmatrix} + \begin{bmatrix} \Delta t \cdot v_O(k+1) \cdot \cos(\theta(k) + \Delta t \cdot \omega(k+1)) \\ \Delta t \cdot v_O(k+1) \cdot \sin(\theta(k) + \Delta t \cdot \omega(k+1)) \\ \Delta t \cdot \omega(k+1) \end{bmatrix} \quad (1)$$

The presented and accepted for realization method is very simple but it has some drawbacks connected with errors. We can distinguish several sources of errors that have an impact on the accuracy of positioning. These sources were divided into two categories: systematic errors and non-systematic errors. Additional odometry errors can be caused by the odometry equations themselves, since they approximate an arbitrary motion as a series of short rectilinear segments. The precision of this approximation depends on the program step. Unequal wheel diameters and the uncertainty about the wheelbase are two dominant sources of errors in odometry [1].

To reduce the errors resulting from the navigation process based on odometry, additional measurement methods are applied. Usually, these are the methods using laser measuring technology. In the case of closed spaces where GPS signals cannot reach, these methods are the most effective. The purpose of this publication is to present the possibilities of laser measuring technology to correct the position of the vehicle.

2. Measuring technology

The exact position of the vehicle can be determined by two methods.

The first one uses the bearings for localization and is known as triangulation. Triangulation is a location method based on measuring the angles to at least three markers on the plane [4]. In the case of two markers on the plane, the position of the point of observation (of the vehicle) is not defined clearly - we know only that it is on the circle that passes through the markers and the point of observation - Fig. 2. Determination of the angle of observation with respect to another pair of markers can be interpreted as finding a second circle. One of the points of intersection of these two circles is the point of observation (the solution is clear, because the coordinates of the second point of intersection result from the coordinates of the marker).

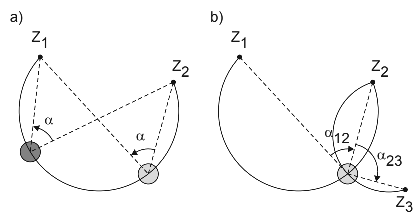

Fig. 2. Illustration of the triangulation method: a) - two markers: ambiguous case, b) - three markers: clear solution

The second method involves the creation of local maps of surroundings of the vehicle by scanning. The map of the area created during the scanning process is compared with a map stored in a computer memory. On this basis, the current position of the vehicle is determined [2, 5, 8, 9].

A two-dimensional vector map is developed according to the following algorithm:

- read of the data,
- division of the received data into objects,
- creation of a list of segments and determination of their parameters,
- matching and linking of objects separated in subsequent scans.

It is assumed that two points $P_1(x_1, y_1)$ and $P_2(x_2, y_2)$ belong to the same object if their distance is less than the predetermined threshold ε, i.e. the condition:

$$\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \leq \varepsilon \quad (2)$$

There are many methods to generate a list of segments for a given set of points. The method of iterative segment generation and the Hough transformation are the most commonly used. The iterative segment generation method is carried out according to the following algorithm:

- for selected points (furthest apart or extreme) (P_a, P_z), there is calculated the equation of a straight line passing through them $Ax + By + C = 0$,
- for all other points there is calculated the distance d from a determined straight line:

$$d_i = \frac{|Ax_i + By_i + C|}{\sqrt{A^2 + B^2}} \tag{3}$$

- if the maximum calculated distance is less than the threshold, then all the points are considered to be collinear,
- otherwise, there is chosen the point P_m with a maximum distance from the straight line and there are determined the equations of two straight lines: the first passes through the points (P_a, P_m) and the other by the points (P_m, P_z),
- the above steps are repeated for each subset.

The second method which enables generating a list of sectors for a given set of points is the Hough transformation. This method has been used for many years in image processing for finding lines located in the image. Its main advantage is that it is resistant to noises in the image. The lines are required to be described in a parametric way. The transform is used most frequently for detecting segments composed of many points [6].

The classical Hough transform is used in the recognition of straight lines. It transforms the so-called Cartesian space into the Hough space, and every point is an image of straight in the Cartesian space. One of the coordinates of this point is the distance from the origin, and the second is the angle of inclination of the normal line to the x axis. In the Hough transform, a certain curve is the equivalent of the point in the Cartesian space. It is created by the points which are the images of all straights passing through this point [3].

The equation of the straight line can be written as normal:

$$c = x \cdot \cos\alpha + y \cdot \sin\alpha \tag{4}$$

where: α - angle between the normal to the straight line and the OX axis, c - distance of the straight line from the point (0,0).

For each point of the XY plane the family of straight lines where the point belongs can be determined, and thus also the family of pairs (α, c). Then a two-dimensional table is created and to each element (α, c) the number of pixels located on the determined by this pair straight is attributed. The set (α, c) having the greatest value, clearly defines the segment consisting of the largest number of pixels.

Experimental studies were carried out inside the building and in the open area. In the external environment, a laser scanner LMS511-10100 PRO by SICK company was applied. This scanner has a scanning range from 0 m to 80 m and a scanning angle of 190°. Other technical specifications are contained in [11]. Among the basic applications of the scanner, one can distinguish:

- use for road traffic for a quick camera control
- use in measuring systems for vehicles;
- measurement and detection in port automation applications, handling terminals, mines and other environments with limited visibility;
- use in protection of access to walls, facades, roofs of buildings with the required high degree of safety (nuclear power plants, military facilities, prisons, etc.)
- use in navigation systems and the control of autonomous vehicles AGV.

In the internal environment, a laser scanner URG-04LX-UG01 by Hokuyo company was used.

This scanner has a scanning range from 20 mm to 4000 mm and a scanning angle of 240°. Other technical specifications are contained in [12].

3. Research range and results

The study was conducted in the open and inside the building. In the case of the open area, it was a driveway to the building, whose diagram and photograph are shown in Fig. 3a. In the case of the building, these were closed rooms and corridors. A fragment of such a corridor is shown in Fig. 3b.

a)

b)

Fig. 3. Scanned object: a) driveway to the building, b) corridor

For measurements in the open area, the SICK laser scanner was used. The data obtained from the measurements were processed using two methods: iterative segment generation and the Hough transform.

Fig. 4 shows the effect of iterative operative methods of generating sections for the example of Fig. 3a.

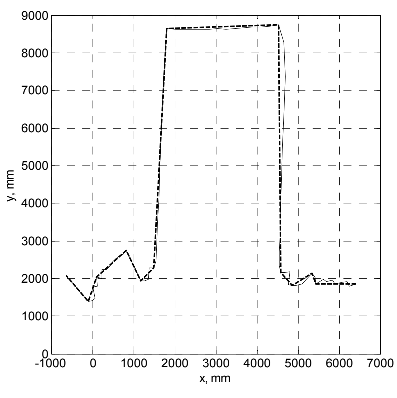

Fig. 4. An example of application of the iterative segment generation method

The results of measurements and calculations for the Hough transform are presented in Table 1 and Fig. 5. In Table 1, the pairs of numbers (α, c) generated from the Hough transform in Matlab are presented.

Tab. 1. Calculated values (α, c)

No.	c, mm	α, deg
1	8700	92
2	4600	1
3	1600	178

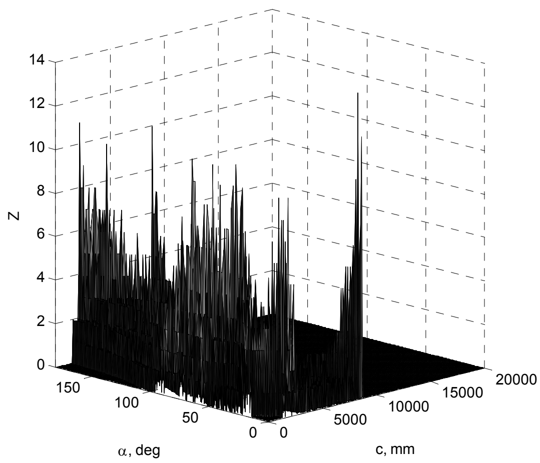

Fig. 5. The results obtained after application of the Hough transform

The dashed line in Fig. 6 shows the segments generated by using the radius *c* and the angle *α* resulting from the conversion by the Hough transform.

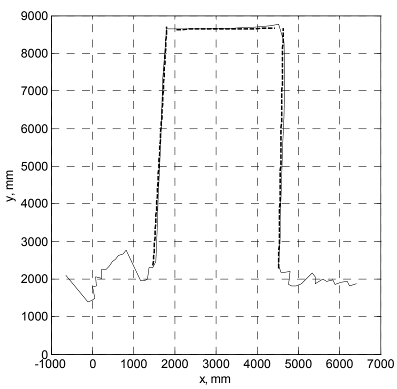

Fig. 6. Images and generated straight sectors obtained after the use of the Hough transform

The above method also has some drawbacks. One of the main disadvantages of this method is the method of selecting the longest segment. The number of points belonging to the segment, not beeing actual length, decides which segment will be selected as the longest one. More sophisticated methods are used for determination of curvilinear sections. The description of these methods can be found in the literature.

In indoor measurements, the HOKyuo laser was applied. This scanner was used to scan the environment and determine the angles between characteristic points imaging the systems of reflectors.

The measurement results are shown in Fig. 7.

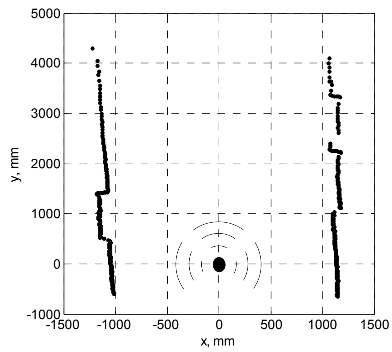

Fig. 7. The image obtained from indoor measurements

Based on the measurement results with the use of the iterative method, the sections shown in Fig. 8 were generated.

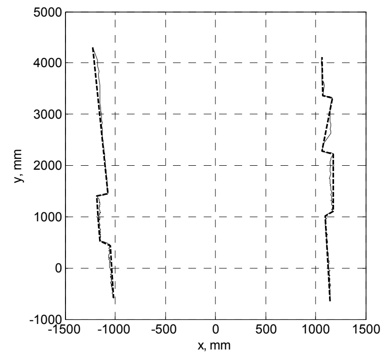

Fig. 8. An example of application of method of iterative sections generating

The results shown in Fig. 9 were obtained by using the Hough transform for calculations.

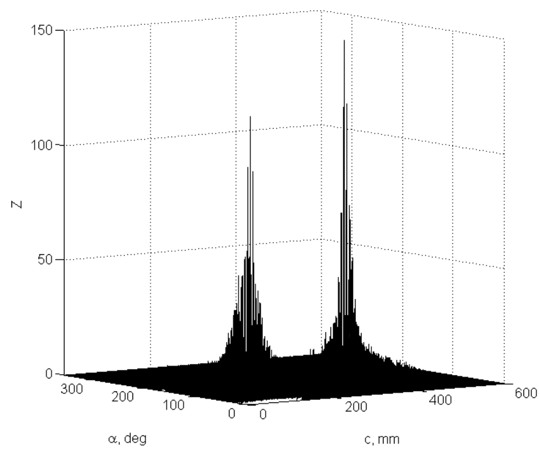

Fig. 9. The results obtained after application of the Hough transform

The dotted line in Fig. 10 shows the sections generated with the use of the radius value *c* and the angle *α* obtained from the transformation using the Hough transform for measurements shown in Fig. 7.

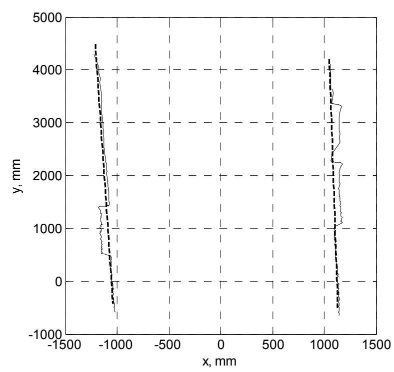

Fig. 10. The image obtained after application of the Hough transform

Triangulation is another method used to determine the position of the vehicle. An example of this method is shown in Fig. 11.

As a result of bearings made by the scanner, a series of data is obtained. These data are then used for calculations, which are run in real time. The sample data and the results of calculations of the coordinates *x*, *y* are presented in Table 2.

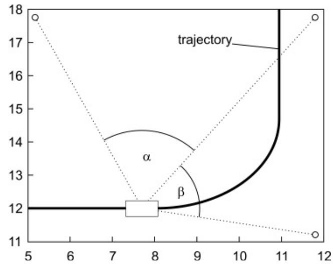

Fig. 11. An example of the trajectory of the vehicle with marked tags and bearing angles

Tab. 2. The data obtained from measurements of angles α and β and the results of calculations of the coordinates x, y

Bearing angles		Calculated coordinates	
α, deg	β, deg	x, m	y, m
57.1	64.8	5.0	12.0
58.6	67.3	6.5	12.0
59.9	70.0	8.0	12.0
61.3	72.5	9.2	12.3
62.0	73.6	9.7	12.5
62.7	74.5	10.0	12.8

This method is sufficiently accurate for practical applications. It is used in factories and warehouse halls. This method requires a clean measuring area, i.e. no obstacles on the route of a reflector and a laser.

4. Conclusions

Odometry is a primary method used to navigate automated guided vehicles. Different types of errors, that occur during the process of navigation, limit its accuracy, and adjustments of the carried out positions are often required. Modern measuring and computing allow obtaining a high accuracy in determining the real position of a vehicle. The methods using laser technology are the most commonly used methods. In closed areas, such as factories or storage halls, the triangulation method is used. This method has a high accuracy and low costs of installation. Its disadvantage is the need to install a large number of tags with a strictly defined position. In the open areas, placement of this type of tags is virtually impossible. Under these conditions, a laser device is used to scan the environment and structure maps. These maps are compared with ambient maps stored in a computer memory. The vehicle position is determined on this basis. A series of calculations including those associated with the Hough transform was carried out in the algorithm of the experimental vehicle traffic control . Transform calculations do not affect the total time of the calculation process.

5. References

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Miroslaw ŚMIESZEK ,DSc, PhD, eng.

Is an Associate Professor at the Rzeszow University of Technology. He received his Postdoc. degree at AGH University of Science and Technology in Krakow, Faculty of Mechanical Engineering and Robotics in 2001. His areas of interest cover automated guided vehicle systems, modern transport systems, robotics and automation in logistics.

e-mail: msmieszk@prz.edu.pl

Magdalena DOBRZAŃSKA, PhD, eng.

Is an Assistant Professor at the Rzeszow University of Technology. She received her PhD degree in construction and exploitation of machines, from the Rzeszow University of Technology in 2007. Her areas of interest are automated guided vehicle systems, modern transport systems, robotics and automation in logistics.

e-mail: md@prz.edu.pl

Pawel DOBRZAŃSKI, PhD, eng.

Is an Assistant Professor at the Rzeszow University of Technology. He received his PhD degree in construction and exploitation of machines, from the Poznan University of Technology in 2008. His areas of interest are automated guided vehicle systems, digital filtering.

e-mail: pd@prz.edu.pl