Computer Engineering, Mechanical Engineering

NAVIGATION SOFTWARE OF AUTOMATED GUIDED VEHICLE

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Abstract: *In the article it has been presented the structure of the control system and measurement data processing of an automated guided vehicle. The basic navigation technique – odometry, which is applied in the automated guided vehicle, has been described, as well as connected with it errors of position tracing. Next the navigation software was shown which enables to design the trajectory of the vehicle movement as well as the registration and reading of the measurement data from the measurement sensors.*

Keywords *:Automated Guided Vehicle, navigation, odometry, odometry errors, Visual C++*

ACM Classification Keywords*: I.2.9 Robotics: Autonomous vehicles, Sensors, J.7 Computers in other systems*

Introduction

Automated Guided Vehicles (AGV) are commonly used in various areas of man's activities. Within two decades one could notice a rapid development of automated guided vehicles which have their applications in totally different areas, for example medicine, industry, transport, defense or agriculture. Some of the vehicles have additional equipment which enables them to perform very sophisticated activities. Presently available vehicles can perform many functions. Depending on the area there are vehicles which can be used in a wide variety of applications, for example in industry, transport (haulage, loading), medicine (automatic nurses, self-propelled wheelchairs), defense (patrol vehicles, vehicles for weapon defusal, vehicles equipped with armament).

The above classification does not reflect in full the applications of the AGV. The aim of their construction is to eliminate dangerous, hard and monotonous work performed by people.

Such a vehicle has been also developed at Rzeszow University of Technology. It is used for the various researches and for the didactics. Some research concerned the issues connected with navigation, especially with the precision of positioning and following the given route.

The aim of the article was to show the basic information connected with analytical navigation, to show already accepted for realization constructional solutions applied in the vehicle and to present the navigation software used to design trajectory, measurement data recording and processing.

Odometry

The base for positioning in the automated guided vehicles is odometry – the analytical navigation. Odometry rely on the determination of the vehicle current position on the base of way covered by the characteristic point K . The analytical navigation uses to determination of the vehicle movement direction angle θ difference of speed of driving wheels the v_L and v_P . The basic idea of this solution was shown in fig.1.

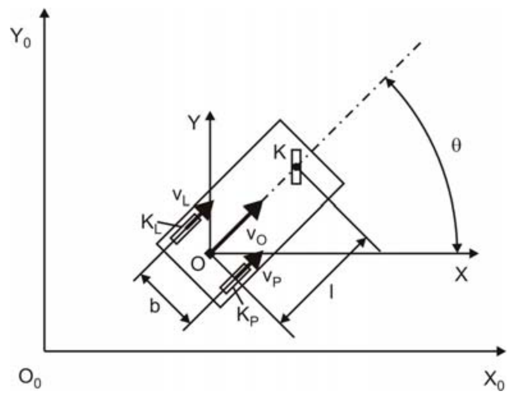

Figure 1. Coordinate system used in analytical navigation

Applied method rely on measurement of the way covered by the driven wheels K_L and K_R and the determination in each iteration of the vehicle movement direction angle θ is used in the vehicles in which two drive wheels independently driven are used to steer the vehicles. The proper differentiation in the rotational speed of these wheels forces the turn of the vehicle around its vertical axis of rotation that goes through the point O and the change in the direction angle θ [Dobrzańska, 2005].

If the position of point O the vehicle in which two drive wheels independently driven K_L and K_P are used to steer the vehicles 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 position of the vehicle in (*k*+1)th iteration is given by the equation:

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

Velocity $v_O(k+1)$ and $\omega(k+1)$ can be determined from the following relations:

$$v_O(k+1) = (v_P(k+1) + v_L(k+1))/2 \quad (2)$$

$$\omega(k+1) = (v_P(k+1) - v_L(k+1))/b \quad (3)$$

where: $v_P(k+1)$ - speed of the right wheel

$v_L(k+1)$ - speed of the left wheel

b - wheelbase of the driven wheels.

Velocity $v_P(k+1)$ and $v_L(k+1)$ can be determined from the following relations:

$$v_P(k+1) = \omega_P(k+1) \cdot r \quad (4)$$

$$v_L(k+1) = \omega_L(k+1) \cdot r \quad (5)$$

where: *r* - radius of the steered wheels

In the above consideration it was assumed that the wheels are rigid and they roll without spin, the contact between the wheel and the floor is a point contact and the radiuses *r* of the driven wheels are the same.

Presented and accepted for realization method is very simple but it has got 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 caused by: unequal wheel diameters, misalignment of wheels, uncertainty about the effective wheelbase (due to non-point wheel contact with the floor), limited encoder resolution, limited encoder sampling rate.
- Non-systematic errors caused by: travel over uneven floor, travel over unexpected objects on the floor, wheel-slippage (due to: slippery floor, over-acceleration, fast turning (skidding), external forces (interaction with external bodies), internal forces (e.g., castor wheels), non-point wheel contact with the floor).

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.

Two dominant sources of errors in odometry are:

- unequal wheel diameters - most mobile robots use rubber tires to improve traction. It is very difficult to manufacture wheels with exactly the same diameter. Furthermore, rubber tires compress differently under asymmetric load distribution. Either one of these effects can cause substantial odometry errors. We denote this error as Ed and define it as

$$E_d = \frac{d_R}{d_L} \tag{6}$$

  where: d_R and d_L are the actual wheel diameters.

- uncertainty about the wheelbase - the wheelbase is defined as the distance between the contact points of the two wheels of the moving vehicle and the floor. Uncertainty in the effective wheelbase is caused by the fact that rubber tires contact the floor not in one point, but rather in a contact area. We denote this error as Eb and define it as

$$E_b = \frac{b_a}{b_n} \tag{7}$$

  where b_a is the actual wheelbase of the vehicle,
  b_n is the nominal wheelbase of the vehicle.
  E_d and E_b are dimensionless values.

Description of construction

Automated guided vehicle designed to transport of cargos executed at Rzeszów University of Technology was the object of investigations. Vehicle has two drive wheels independently driven which are used to start and steer the vehicle. The object of investigations has onboard PC, cards of data acquisition, and control-measuring equipment. The vehicle is built on the base of the three-wheeled construction with two drive wheels and one independent rotating wheel. Such solution allows the vehicle to be very maneuverable and, at the same time, to have simple steering and movement direction control through the constant monitoring of the rotational speed of both wheels.

Technological parameters of the vehicle are :

- weight of the robot ready for work including battery is 200 kg,
- it can move at speed 1m/s,
- two direct current motors, each with supply voltage 36 V, were used to drive road wheels, nominal moment 0.55 Nm at speed 3200 rpm, maximum current 27 A, maximum moment 2.8 Nm,

- there are three series connected batteries that supply the robot with voltage 36V, their total capacity 150 Ah,
- the vehicle is able to carry loads up to 100 kg.

Robot supporting structure is created by the steel frame made of the structural sections where all the subassemblies were placed (fig.2). The drive wheels are made of metal and covered with vulcanized rubber rim. The wheel is fixed to the hub placed on the axle going out of the reducer that is driven by the motors through the belt - gear transmission. The gear transmission ratio is 1:2 and the reducer transmission ratio is 1: 40. The self-adjusting wheels are fixed to the robot structure in a way that allows the turn around their own axle (perpendicular to the robot base).

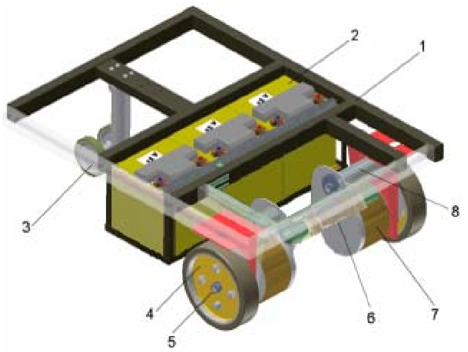

Figure 2. Lay- out of the particular subassemblies: 1 - . robot supporting structure, 2 batteries, 3 - supporting self-adjusting wheel, 4 - drive wheels, 5 - encoder, 6 – cogged pulley, 7 - reducer, 8 - driving motors

The elements used to steer and supply the robot driving motors are the servo-amplifiers SCA-SS-70-10. Automated guided vehicle has two encoders used to measure angular displacements that are to measure an angle and an angular velocity. The base for positioning in this type of vehicle is odometry which introduces some errors. To eliminate these errors the additional sensors allowing to improve the accuracy of vehicle positioning are used in the contemporary vehicle. Such sensors are the laser, sonar and gyro enhanced orientation sensor.

The control system and measurement data processing of an automated guided vehicle

The vehicle movement along the given trajectory is controlled by the onboard guided system. It includes: the onboard PC, cards of data acquisition, measurement sensors and computer software with implemented guided algorithm.

The steering voltage in each measure is generated by the computer on the analog output of the measurement card. Then they are fed on the input terminals of the servo-amplifiers. Inside the servo-amplifier there is the system of the feedback whose aim is to keep the constant rotational speed of the supplied electric motor. This speed depends on the voltage signal from the measurement card of the computer.

Information gathered from the measurement cards is used by the application which works in the Visual C++ environment (fig.3). The application itself takes information, processes it and generates the guided signals. The application was written in a way which enables the users who do not know the software language or the details connected with the vehicle construction and the cooperation of the subsystems to design the trajectory, the vehicle movement on the designed trajectory, reading and analysis of the measurement data obtained from the sensors installed on the vehicle.

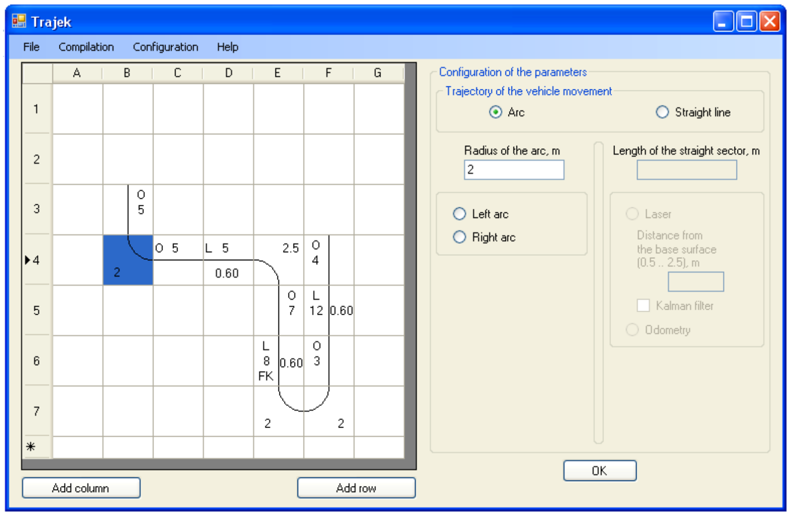

Figure 3. The view of the main window

In the application one can choose some of the basic tasks: trajectory design, edition of the designed trajectory, compilation, reading of the measurement data, analysis of the measurement data.

The application enables for the movement according to the designed earlier trajectory. The trajectory may consist of the elementary segments such as straight line or an arc (fig. 4), for which we can define the right parameters.

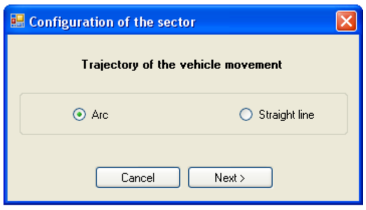

Figure 4. Window of choice of the elementary segment

In case of the straight sector the application enables for the choice of guiding the vehicle: analytical navigation, following along the base surface on the basis of the measurements from the laser sensors. It is also necessary to define the length of the straight sector (fig. 5a).

a) b)

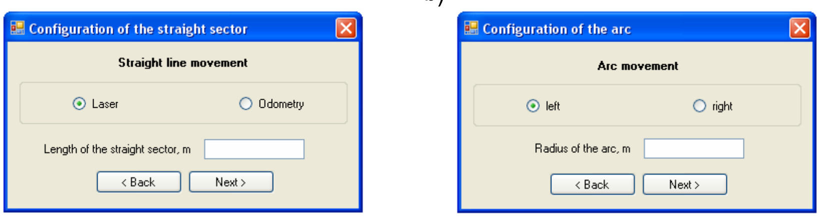

Figure 5. Windows of configuration of the elementary segments

Additionally, when the user chooses the straight sector where the vehicle is to be guided along the base surface on the basis of the reading from the laser sensors, here is a possibility to guide the vehicle in a given distance from the base surface on the basis of the reading from the laser sensors which were not subjected to filtration, he can also choose the filtration option after which the measurements from the laser sensor will be filtered in a real time with the application of the Kalman filter. In case of the following along the base surface it is necessary to quote the distance from the base surface in which the vehicle will be guided. Due to the measure range of the laser sensors the value can change from the 0.5 to 2.5 m. It is also necessary to quote the side where the base surface will be placed. After choosing the right option the measurement of the distance from the base surface will be done from one of the two sensors installed on the both sides of the vehicle (fig. 6).

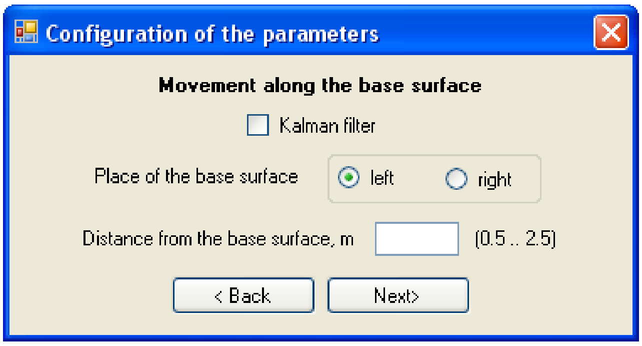

Figure 6. Window of configuration of the straight sector where the vehicle is to be guided along the base surface

After choosing the second option – an arc movement - it is necessary to define whether the vehicle should move in the left or in the right. The radius of the arc should be defined as well (fig.5b).

After choosing the trajectory there is a possibility to write it in. The program enables for the modification of the already designed trajectory by changing the parameters of the chosen elementary sector, change of the sector, and also adding or removing the sector. In order to simplify the analysis of the trajectory, at each element there is a detailed description. It can be obtained by its marking.

This application enables also for the compilation of the designed trajectory. This compilation consists in the check of the correctness of the designed trajectory as for the errors which result from the logical continuity of the trajectory (fig. 7).

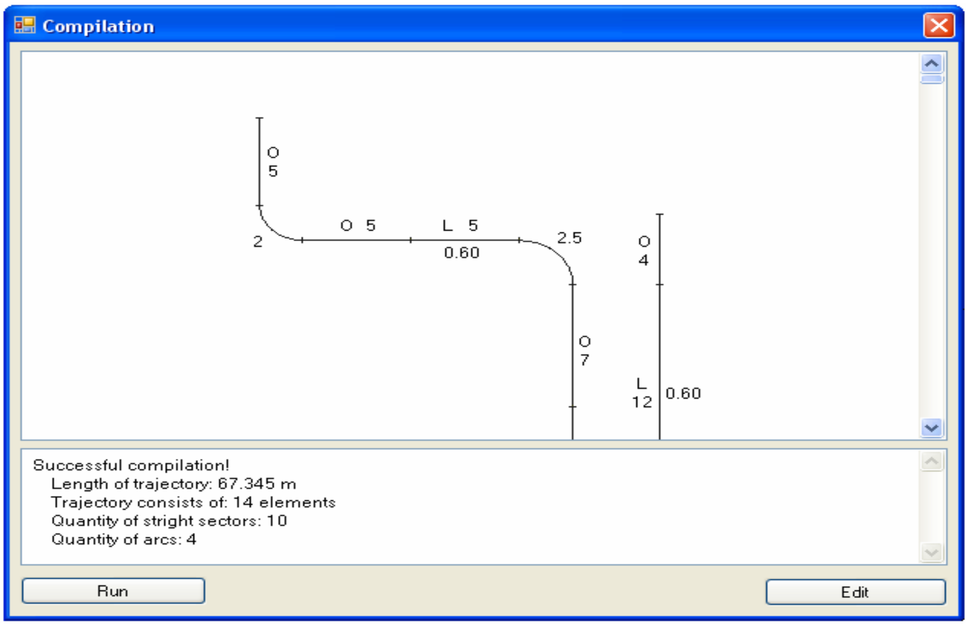

Figure 7. Result of compilation of trajectory

The software enables the reading of the measurement data from the installed in the vehicle sensors. The data is then written in the file. Next it can be analyzed. The application enables then for the edition of the written data, filtering them with use of digital filters, as well as the generating of the chosen graphs (fig. 8b). The user has a possibility to choose what measured quantities will be written in the file (fig. 8a).

a) b)

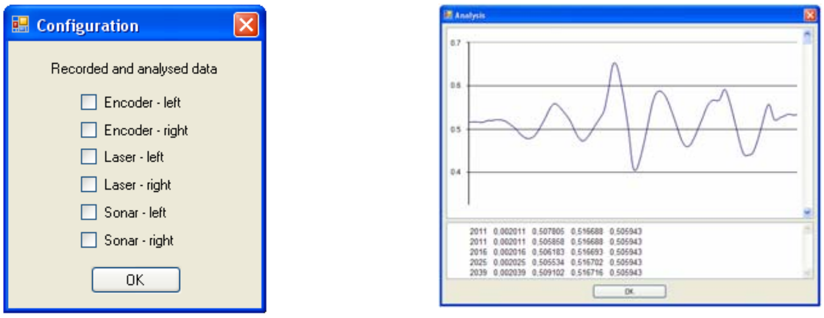

Figure 8. Window of choice of the measurement data designed to record (a) and window of analysis data (b)

To start or to stop the vehicle as well as to give the defined trajectory along which the movement should be performed the second off-board computer is used and it performs the primary function. Two-sided communication of the vehicle with the primary computer is wireless by means of the radio. The application of such a solution was done due to the fact that the creation of the mobile network with the use of the cables is practically impossible. When we apply the cable the vehicle mobility is limited to the length of the transmission cable. In the research for the two-sided communication with the primary computer the stationary wireless network has been used.

Conclusion

The article presents the software written in Visual C++. The software is the part of the system which has been created on need the vehicle. The software will be extended and well-fitting to needs of modified vehicle and carried out on him the investigations.

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