The use of digital filtration methods in AGV laser navigation systems

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Abstract. Recognition of the surroundings of automated guided vehicles (AGV) is one of the basic factors ensuring their proper movement in the field. The aim of the article is to present the use of a laser scanner to locate the position of objects in the vehicle's surroundings as well as to present the results of simulation of the analyzed methods of filtering the measurement results.

1. Introduction
AGVs play an increasingly important role in the production environment and their use significantly facilitates the implementation of operations included in the production process, optimization of logistic flows in the enterprise and also improves warehouse management. Their use increases the efficiency and capacity of transport. AGV vehicles significantly reduce the number of errors related to internal transport and allow you to track the flow of materials in the company. Also relieve the employees so they can focus on tasks which are more demanding and complex than the internal transportation of materials.

A variety of navigation techniques are used to drive an AGV and these techniques can drive the vehicle along a preset and physically determined route or along a computer-generated virtual route. In a true trajectory navigation system, the vehicle follows a strictly-physically defined route. This route can be determined by means of an induction loop, an optical loop or a magnetic loop. In the navigation system using virtual trajectories, the vehicle has its own extensive control system with a sufficiently large memory. The memory includes the map of the area and the route along which the vehicle is traveling. Using data from appropriate sensors the control system determines the current position of the vehicle and further motion parameters. The basis for determining the position in this type of navigation is odometry - computational navigation [1]. This method of determining the position of the vehicle is burdened with many errors. Additional systems are used in modern vehicles to correct these errors. Most often, in the conditions of industrial halls and buildings with well-known architecture, laser methods are used, less often magnetic or optical [2, 3]. In the open space the GPS method is most often used for navigation but very often additionally supported by laser methods, mainly used to detect obstacles. The decision to make an AGV move is usually based on knowledge of the surrounding environment. This information is contained in the form of the so-called maps. As the real environment is usually very complex and often poorly structured maps take into account key features such as the positioning of obstacles in space. To create environment maps are used, inter alia, laser scanners. In the scanning process, a map of the area is determined which in turn is compared with the map saved in the computer's
memory. On this basis, the current position of the vehicle is determined. Many methods are used to create maps of the environment based on measurements from laser scanners. For this purpose, methods of generating simple lines are used, among others. There are many methods for generating a list of segments for a given point set. One of the most commonly used is the Hough transform [4, 5]. In the basic version, a transform allows one to obtain information about straight lines in an image. The image must be pre-processed and edge detected with a detector such as Sobel, Prewitt or Canny [6-7]. The pretreatment is performed with the use of appropriate digital filters. They are used to remove distortions and noise in the image, enhance some image elements (e.g. edges), improve the visual quality of the image, reconstruct the image. Performing the pretreatment with digital filters contributes to obtaining better final results after applying the Hough transform. The mentioned use of digital filters is not the only one. Digital filters are widely used in many areas. Examples of their use in industry are presented in the works [8-10].

The aim of this article is to present the use of digital filtering in vehicle laser navigation and more precisely in the process of generating sections that form a map of the surroundings.

2. Designating the scanned area

The Hough transform is one of the methods that allows to generate a list of segments for a given set of points. This method has been used for many years in image processing to find lines in an image. The transform is most often used to detect the segments consisting of the largest number of detected points. The subject of the analysis in the Hough transform is the set of points \( \{(x_1, y_1), \ldots, (x_n, y_n)\} \) occurring in the image. Each of the points \((x_i, y_i)\) is converted into a sinusoid in the parameter space \( \rho, \theta \) (Figure 1) using the formula 1.

\[
\rho = x\cos\theta + y\sin\theta
\]  

where:

\( \theta \) – the angle between the normal to the given straight line and the \( OX \) axis,

\( \rho \) – distance of a given line from the point \((0,0)\).

![Figure 1. The line represented by \( \rho, \theta \)](image)

The number of intersections of sinusoidal curves \((n_\omega)\) increases squarely with increasing number of points \((n)\) in the image and is given by the formula \( n_\omega = \frac{n(n-1)}{2} \). In order to reduce the computational complexity of the described algorithm, quantization of the parameter space \( \theta, \rho \) is used (depending on the required accuracy, an appropriate level of representation is selected). The parameter \( \theta \) is limited to the interval \([0; \pi]\) and the parameter \( \rho \) to the interval \([-R; R]\), where \( R \) is the image diagonal. As a result of the Hough transform an array of the so-called accumulator the individual cells of which inform about the number of points lying on a given line. In the next step the array is examined for large values in order to find all the most probable lines.

As mentioned earlier, in order to apply the classical Hough transform the input data must be properly prepared. The first step is to apply an appropriate noise removal filter. The second step is to apply contour filters for edge detection.

Obtaining binary information from the image is possible using edge detection algorithms. This is possible thanks to the following filters: Sobel, Prewitt or Canny. Most edge detection methods are based on finding places in the image where there are large differences in values between neighboring pixels.
directional derivatives are calculated for this purpose). The principle of operation of this type of algorithms makes them susceptible to the presence of noise in the image which causes detection of edges in places where they are absent. This in turn affects the detection of false lines by the Hough transform. In order for the edge detection algorithms to function properly, it is necessary to reduce the noise in the images. For this purpose appropriate filters are used. Examples of filters include: Gaussian, arithmetic mean, anisotropic diffusion, Frost, Lee, bilateral, vector median.

Detecting edges in an image significantly reduces the amount of data and filters out information that may be perceived as less significant while preserving important properties of the structures in the image. There are many edge detection methods but most of them can be grouped into two categories either using the first derivative study (gradient methods) or using the second derivative study. The methods of the first category detect edges by searching for the maxima and minima of the first derivative of the image. The methods of the second category look for a zero crossing in the second derivative of the image. The Laplace operator's zero-crossing or the zero-crossing of a nonlinear differential is generally used to find the edge. The first type of operators include, among others: Prewitt, Sobel, Canny [11-13]. The second type includes: Marr-Hildreth, zero crossing detection of the second derivative of the image luminance change.

Since the subject of further considerations were gradient methods, their characteristics are presented below.

The Sobel algorithm uses two filtering masks a horizontal $S_x$ and a vertical $S_y$. The $S_x$ component is the gradient toward the rows and the $S_y$ component toward the columns. The value of the edge response and its direction are determined according to the formulas (2) and (3):

$$G_{mag} = \sqrt{(S_x)^2 + (S_y)^2} \quad (2)$$

$$G_{dir} = \arctan \frac{S_y}{S_x} \quad (3)$$

The operation of the Prewitt algorithm differs from the Sobel algorithm only in the masks used. In the case of the Canny algorithm, the first step is to reduce the noise with the Gaussian filter and then to determine the first derivative of the image as the derivative of this function. Both actions are performed with one-dimensional masks acting separately in the direction of the rows and the direction of the columns. The value of the first derivative for the vertical mask is given by the formula:

$$G_\sigma(x)' = \left( -\frac{x^2}{\sigma^2} \right) \cdot e^{\frac{x^2}{2\sigma^2}} \quad (4)$$

where:

- $\sigma$ - standard deviation;
- $x$ - pixel position in the mask in the direction of the rows.

Similarly, according to formula (4), the values for the horizontal mask are determined. As a result of the image convolution with each of the masks we obtain gradient components in two directions perpendicular to each other. The response values and the edge direction are calculated according to the formula (2) and (3). The next step is the process of "suppressing" local non-maximum suppression. The edge pixel will be the one for which the value of the edge response will be greater than the value of neighboring pixels lying in the same direction. The final step is a hysteresis binarization procedure using two thresholds a high $Th$ threshold and a low $Tl$. The images created at this stage are used when grouping edge pixels using the edge tracking method.

3. Experimental research

In the experimental part of the article the influence of the selection of the digital filter and the edge detection filter on the results of the classical Hough transform was investigated. The image obtained from the recorded measurements with a laser scanner was used for the tests (Figure 2). On the other
hand, the analysis of the effectiveness of individual filtration methods was based on the functions available in MATLAB describing individual filtration methods.

![Figure 2](image)

**Figure 2.** Results obtained on the basis of measurements with a laser scanner

In the first stage of preprocessing for the Hough transform as a step preceding the edge detection the following filters were implemented: Gauss, anisotropic diffusion, bilateral, vector median. Since no significant differences in their operation were noticed for the analyzed image, it was decided to utilize the commonly used Gaussian filter for further research. In the next step, edge detection was performed using one of the three contour filters analyzed: Canny, Sobel, and Prewitt. The evaluation criterion that was used to select the appropriate edge detection method were the results obtained in the last stage of the algorithm, namely after applying the classical Hough transform. The parameters that were subjected to comparison are the lengths of the generated segments in relation to the total length of the segments present in the analyzed image. Figure 3 shows the result of the Canny edge detection method and the accumulator calculated on this basis.
The next step was to find local maxima in the accumulator. This operation allows to determine the most likely straight lines, omitting all that could mean the same line in the image. The identified local maxima are presented in Table 1. The highest values were obtained for the given pairs and they mark the segments consisting of the greatest number of pixels.

Table 1. Calculated values ($\rho$, $\theta$)

| $\rho$ | $\theta$ |
|--------|----------|
| 969    | 91       |
| 988    | 271      |
| 587    | 91       |

Figure 4 shows the sections generated with the use of the radius $\rho$ and angle $\theta$ obtained from the transformation using the Hough transform for the measurements presented in Figure 2. The obtained results refer to the variant in which the Canny filter was applied.
Figure 4. Image obtained after applying the Hough transform

Another edge detection filter used was the Sobel filter. Figure 5 shows the result of Sobel edge detection and the calculated accumulator.

![Figure 5](image)

Figure 5. Edges detected in the image using the Sobel filter (a); calculated accumulator (b)

Following the example of the previous filter local maxima were found in the accumulator. The identified local maxima are presented in Table 2. They mark the segments consisting of the largest number of pixels.

| Table 2. Calculated values ($\rho$, $\theta$) |
|-----------------|-----------------|
| $\rho$ | $\theta$ |
| 963 | 89 |
| 987 | 269 |
Figure 6 shows in green the sections generated using the value of the radius $\rho$ and the angle $\theta$ obtained from the transformation using the Hough transform for the measurements presented in Figure 2. The obtained results refer to the variant in which the Sobel filter was applied.

Figure 6. Image obtained after applying the Hough transform

The third variant was considered a variant that uses a Prewitt method. Figure 7 shows the result of the edge detection using the Prewitt method and the accumulator calculated on this basis.
Figure 7. Edges detected in the image using the Prewitt filter (a); calculated accumulator (b)

Also in this case, local maxima were found in the accumulator. The identified local maxima are presented in Table 3. They mark the segments consisting of the largest number of pixels.

Table 3. Calculated values \((\rho, \theta)\)

| \(\rho\)  | \(\theta\) |
|----------|----------|
| 963      | 89       |
| 986      | 269      |
| 590      | 91       |

Figure 8 shows the sections generated with the use of the radius \(\rho\) and angle \(\theta\) obtained from the transformation using the Hough transform for the measurements presented in Figure 2. The obtained results refer to the variant in which the Prewitt filter was applied.

Figure 8. Image obtained after applying the Hough transform
As the conducted analysis concerned data obtained from measurements with a laser scanner, which are used to create a map for an AGV vehicle, an important criterion was the effectiveness of detecting sections in the analyzed image. The application of the Hough transform with the Prewitt edge detector turned out to be the most advantageous for the analyzed image. Obtained in this case 92% mapping. The use of the Hough transform with the Canny filter resulted in a 77% mapping, while the Sobel filter provided a 78% mapping.

4. Conclusions
This paper presents the application of the Hough transform in determining the map of the AGV’s surroundings. The AGV vehicle was moving inside the building and was equipped with a laser scanner. The purpose of using the Hough transform was to find the characteristics of the environment in the form of wall fragments. Wall sections were detected using the classic Hough transform method. Its use was preceded by the use of an appropriate edge detection filter. Three filters were analyzed in the research: Sobel, Prewitt and Canny. The Prewitt filter turned out to be the most favorable for the case under consideration. In further research, it is planned to use other variants of the Hough transform in order to analyze the environment of the AGV vehicle in terms of the presence of geometric figures described by other parameters.

5. References
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