Vision-Based Automated Guided Vehicle for Navigation and Obstacle Avoidance

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Abstract - This paper proposed a navigation control system for a Vision-Based Automated Guided Vehicle (V-AGV) by detecting and recognizing line tracking with Universal Serial Bus (USB) camera. In this research, a mobile robot, a laptop computer and a low-cost USB camera are used as the main components of the system. The vision-based navigation system structure is composed of several processes; these processes consist of guideline detection, sign detection, obstacle detection and obstacle avoidance. In order to demonstrate the results of this proposed navigation system, a mobile robot platform as been developed. The results obtained from several experiments have shown that the USB camera has performed very well in executing the proposed algorithm. The proposed V-AGV system has the capability of following the constructed line properly, detecting a junction, identifying the existence of floor sign close to the guideline and most importantly be able to avoid collision with obstacles.

Keywords — Vision-based Autonomous Robot, Guideline Navigation, Obstacle Detection, Line following, Machine Vision Application

I. INTRODUCTION

The Automated Guided Vehicle or Automatic Guided Vehicle (AGV) is one kind of intelligent mobile robot, which can move along the guideline conveying the parts to destination, self-determined, is widely used in industrial field, community service and in office environments [1]. With the implementation of the AGV system especially in advanced manufacturing system, it will help to reduce costs and increase efficiency. Usually the implementation of AGV is in the Flexible Manufacturing Systems (FMS) in order to integrating machinery or manufacturing cells, which need material transfer.

In the development of AGV, there are two main classifications of, guiding with lines and without lines. In the first system, most AGV are tracking buried cables or floor painted guides-paths. One of the most popular navigation systems is based on the magnetic tape to form guide path and the AGV is fitted with the appropriate guide sensor to follow the path of the tape. Another form of an AGV navigation system is without using any path or guideline on the floor such as based on the laser target and inertial navigation.

The AGV systems in general, consist of a computer software and technology that are the “brains” behind the AGV. The advancement in computer technology, the application of vision system has a very significant impact in developing the system that are flexible, efficient and low maintenance cost especially in mobile equipment [2]. In other hand, the AGV system that utilized a vision-based sensor and computer image processing for navigation can make the system more flexible, more larger amount of information can be processed and make the system operation robust. For example, the single image captured by camera sensor on the top of AGV can be used to identify guideline, signboard, landmarks and obstacle [3]. The AGV that utilized a vision-based sensor for navigation is known as Vision-based Automated Guided Vehicle.

There are numbers of issues that had been discussed in present research works of the V-AGV that implemented guideline in their navigation, most of them are computer vision techniques. Firstly, to determine what the suitable camera is that can be used. There are many options available, either CCD camera or USB CCD camera. The selection of the vision-based sensor is depending on the research requirement and the suitability of the system itself [4].

Secondly, related to the line detection and recognition. Amongst the issues that had been looked into including on how to identify line, crossing line and broken line. Some researchers prefer to use template matching for crossing line recognition and wavelet transformation technique for the guideline detection purpose [5].

Thirdly, is regarding on the obstacle detection and avoidance. Generally, there are two categories of obstacle; moving and static obstacles. Examples of moving obstacle are human and another AGV, meanwhile a static obstacle is a box. In particular research, AGV’s operator needs to remove obstacles that obstruct their route and sometimes be able to avoid them in order to prevent collision. Additional sensors such as sonar sensor can also be used to accomplish this task.

Fourthly, the issue is on the sign detection or landmark recognition [6]. This is very important since V-AGV routes are not being programed, but it was determined by the operator. The directions are based on the special signs or landmarks, which are developed along the V-AGV routes. These signs are located at each junction of route in which to assist which direction to go.

The final issue is about the technique of navigation control systems. It combines all the mentioned issues with a proper and realizable method. A regular navigation, without obstacle is known as main navigation meanwhile when navigated to avoid obstacle, it is called free-collision navigation or conflict-free navigation. This navigation can be categorized as a special navigation [1].
This paper will describe the navigation control system into several parts: line detection algorithm, sign detection algorithm, obstacle detection algorithm and conflict-free navigation algorithm. Then, all these will be incorporated into the V-AGV navigation control systems that include main navigation and special navigation. Simulation and experimental works have been conducted in each task in order to obtain the results as required. However, this paper will present detailed results only from experimental part. In this research works, the V-AGV platform has been designed and developed to carry-out the related experiments.

II. DESIGN AND IMPLEMENTATION OF V-AGV

This part describes in detail the design and implementation of V-AGV system for navigation and obstacle avoidance. However, speed control strategy will not address details in this paper.

A. Mobile Robot Platform Configuration

In order to demonstrate the results of this proposed navigation system, a mobile robot platform as been developed. It’s consisting of hardware design, motion control system, vision system and serial communication. The mobile robot powered by two 10 Watt Brushless DC Motor, one 360 degree rotating caster wheel and two of 12 V 4 Amp batteries. Programmable Intelligent Computer (PIC) microcontroller has been selected as a controller to control and monitoring the overall components of the V-AGV system. In this project, the commercial Machine Vision Software has been used on the vision system part and serial communication is implemented to communicate between mobile robot motion control and machine vision software.

B. Model of Navigation System

The navigation control system for the V-AGV consists of two modules of navigation as shown in Fig. 1, they are:
- Main navigation module
- Conflict-free navigation module

Both navigation modules are constructed from three algorithms that have become a guidance to determine speed of the V-AGV. Guideline detection, sign detection and obstacle detection gain some predictive of knowledge from environment via USB camera. The situations analyzed in each stage of algorithm will be inputs to main navigation module in order to get the suitable velocity based on the current situation environment of the V-AGV.

If an obstacle appears on the guideline and the width of that obstacle can be measured, the conflict-free navigation will be executed and main navigation module in idle process. Conflict-free navigation is a different form of main navigation since it intent to generate new path in order to avoid obstacle and then return to the original guideline. However, main navigation module or conflict-free navigation module will send command to the motor controller through serial communication. This control system approach is a close-loop process.

C. Line Detection Algorithm

The V-AGV requires a guiding system for navigation. A low cost guideline has been designed and implemented as a guiding system for this project. This guideline detection algorithm will be a main reference throughout navigation. It has been built so that the V-AGV can identify a guideline and then move continuously following the line.

The guideline consists of two different layer and both have two opposite colors. The first guideline is in white or bright like yellow color. It has been fixed permanently on a flat floor surface. The second guideline is in black color and been fitted on a first guideline layer and located along the middle part of that layer. There are seven types of guidelines have been designed and constructed to be used in the experimental work. They are:
- Type 1 Straight guideline
- Type 2 Crossing guideline
- Type 3 Turn left guideline
- Type 4 Turn right guideline
- Type 5 Straight and left guideline
- Type 6 Straight and right guideline
- Type 7 Junction guideline

Line detection algorithm can be divided into the four steps, they are:

System Initialization. It’s includes parameters setting for USB camera, image processing and program control.

Image pre-processing. The image captured by the camera will be divided into five sub Region of Interest (ROI). The linear smoothing technique is applied in order to improve the image quality by averaging all input images with gray values for border treatment at the image edge.

Measuring the Width of the Guideline. For each ROI, image processing technique are applied to extracts straight edges which lie perpendicular to the major axis of a rectangle of ROI and measure the distance between consecutive edge points. As a result of this process, the coordinate edges value (RowEdge, ColumEdge) and the guideline width (Distance) in all ROI’s can be obtained.

Recognition and classification of guideline. To recognition of the guideline, it can be obtained from the following rules,
if \((\text{Distance}(n)[j] > \text{Minimum width of guideline and Distance}(n)[j] < \text{Maximum width of guideline and Edge amplitude of the edge } [j]<0 \text{ and Edge amplitude of the edge } [j+1]>0)\)

so
\[S_{x,y}(n)=\text{RowEdge, ColumnEdge}[j+1]-(\text{Distance}[j]/2)\]

Where \(S_{x,y}(n)\) is a center point of guideline on the \(n^{th}\) – ROI.

In the step of guideline classification, it has a function to determine a pattern or a type of current guideline that has been processed. There are eight possibilities of guideline types. At each ROI, if there is a guideline been detected crossing that ROI, it will be marked as active or labeled as ‘1’. The combination of ROI illustrates type of guideline, either straight, crossing or others. Combinations of labels are as follow; [ObstacleExits, LineExitsU, LineExitsS, LineExitsL, LineExitsR]. If a combination of label is [0,1,1,1], this means that a guideline is in processed by the algorithm is T-junction. So, this simply tells the V-AGV that in front of it there is a junction to the left or to the right.

**D. Sign Detection Algorithm**

Vision is a powerful tool which allows a robot to recognize markers, sign and any landmark that have predetermined characteristics. A sign symbol that been placed on the floor, is used as a direction in the V-AGV navigation. Certain symbols have been opted and designed to facilitate vision system detection. They will be an indicator for the V-AGV to determine which route it must take if they met a crossing guideline or any necessary action throughout their journey. This make the system autonomous and navigated without pre-programmed. In other word, it relies on the signed that been located by an operator along that path. At the same time, that symbols must be understandable to human being. The location of the signs has been fixed on the right side of a guideline.

A specific sign has been designed for this research work. That design must be recognizable, very clear to a vision and most importantly understandable by a human. It has been drawn using computer software and been printed on a white paper. Fig. 2 displays all the signs that help the V-AGV to determine it navigation route when arrive at a junction. That design consists of two elements;

- **External simple shape (a circle)**
- **Internal symbol (directional arrow with different orientation and special stop sign)**

![](image1)

**Figure 2.** The directional arrow signs and stop sign.

Sign detection by using area center of two regions is introduced. This method using the calculation of area centre of external circle of sign region and arrow symbol region. After that the position of center symbol and center external circle are calculated. To identify the symbol, we use the vertical distance, \(\Delta_{\text{down}}\) and horizontal distance, \(\Delta_{\text{down}}\) between two points; as shown in Fig. 3. Each distance is defined as follow;

\[\Delta_{\text{down}} = \text{rowcircle} - \text{rowsymbol}\]
\[\Delta_{\text{down}} = \text{columncircle} - \text{columnsymbol}\]

There are four possibilities;

\(\{\Delta_{\text{down}} > \Delta_{\text{down}} \text{ and } \Delta_{\text{down}} < \Delta_{\text{down}}\}\), means directional arrow sign to left.
\(\{\Delta_{\text{down}} < \Delta_{\text{down}} \text{ and } \Delta_{\text{down}} < \Delta_{\text{down}}\}\), means directional arrow sign to right.
\(\{\Delta_{\text{down}} > \Delta_{\text{down}} \text{ and } \Delta_{\text{down}} > \Delta_{\text{down}}\}\), means directional arrow sign to straight forward.
\(\{\Delta_{\text{down}} > \Delta_{\text{down}} \text{ and } \Delta_{\text{down}} > \Delta_{\text{down}}\}\), means directional arrow sign to return back.

**Figure 3.** Center area of circle and symbol of sign.

**E. Obstacle Detection Algorithm**

In this research works, obstacles are assumed to be lied on the floor, along the path or close to it that might disrupt V-AGV motion. Obstacle might be placed exactly on a guideline or may be just adjacent to it. In this section, a simple method is used to detect an obstacle on the guideline while the AGV is on moving. This research proposes a simple approach to detect an obstacle on the guideline. In any cases, we have considered that an obstacle appears if guideline detection image processing cannot detect any value of pixels which are \(S_{x,y}\).

Meanwhile, an obstacle distance to the V-AGV can be acquired through the transformation from pixels of images to real coordinate systems. Through several experiments that have been carried out, the followings are the parameters that have been used to determine obstacle distance to the vehicle, as indicated in Figure 3.22.

- \(l_{\text{max}} = \) Minimum distance on real coordinate can be captured is equal to 22.0 cm from camera position.
- \(l_{\text{max}} = \) Maximum distance on real coordinate can be captured by camera is equal to 71.0 cm from camera position.
- \(h = \) Camera higher from the floor= 33.0 cm
- \(\alpha_1 = \tan (h/ l_{\text{max}}) = 56.0\) degree, this angle is depending with camera orientation and high position. Camera orientation is fixed.
- \(\Theta_1 = 30.0^\circ\) = 34.0 degree
- \(\Theta_1 = \tan^{-1}(h/ l_{\text{max}}) = 24.9\) degree
- \(\Theta_2 = P/S_y \times (90^\circ - \Theta_1\times \Theta_3)\)
- \(P_x = \) distance of obstacle on image (in pixels) along y axis of image
- \(S_y = \) maximum distance on image (in pixels) = 240 pixels
- \(y = \) real obstacle distance from camera position
By using all those parameters, the real distance of obstacle from point zero, y, can be calculated using on Equation (1).

\[ y = h \times \tan \left( \theta_i + \theta_j \right) \]  

In order to get actual obstacle width, (w), parameters as in Fig. 5 need to be computed earlier, and then been calculated using Equation (2), Equation (3) and Equation (4). Those parameters are given as:

- Length of capturing areas is fixed at 49.0 cm,
- Half width of capturing area is is fixed at 14.5 cm,
- \( \beta = \tan^{-1}(\text{half width capturing areas/length of capturing areas}) \)
- \( \gamma = \tan^{-1}(14.5 \text{ cm}/49.0 \text{ cm}) = 16.48^\circ \)
- \( S_i = \text{image width} = 320 \text{ pixels} \)

\[ w = x_1 + x_2 \]  

\[ x_1 = y_1 \times \left( \frac{P_1}{0.5S_i} \right) \times \tan \beta \]  

\[ x_2 = y_2 \times \left( \frac{P_2}{0.5S_i} \right) \times \tan \beta \]  

This path generation involves two phases of control algorithm, which are rotation motion phase and translation motion phase. In the rotation motion phase, there is two opposite direction of magnitude and is stated in Equation (5) and Equation (6). The first rotation angle, \( \Theta(t_{ij}) \) occurs at the point a, c and e. By looking from a top view, a rotation direction is in clock wise direction. Meanwhile, the second rotation angle, \( \Theta(t_{ij}) \) happens at the point b, c and d.

\[ \Theta(t_{ij}) = \tan^{-1}\left( \frac{w+\Delta w}{y} \right) \]  

\[ \Theta(t_{ij}) = -\Theta(t_{ij}) \]  

The translation motion phase involve two different distances. Firstly, it happens between point a, point a-b and point d-e with a translation about \( l_{max} \). value obtained from Equation (7). Secondly, it happens between point b-c and point d-c with a translation about \( l_{max} \). This value is constant and been fixed into the system. At this stage, rotation and translation motion will keep repeating until a vision system discovers an original guideline. After performing rotation motion at a point e, the system will use main navigation system again to continue it journey.

\[ l_i = \sqrt{y^2 + (w+\Delta w)^2} \]
III. EXPERIMENTAL RESULTS

This part presents the results of experiment in this research. Each experiment in this project is in the controlled environment. It includes the specification of line design and source of lighting. Machine vision software and Microsoft Visual Basic are integrated to perform as vision based AGV navigation control system. The system captured image directly from USB camera in a real-time, process an image with machine vision software, analyze the information with a proposed algorithms and sending the result to the mobile robot motor controller via serial interface of laptop computer. The overall whole control system consists of line detection, sign detection, main navigation, speed control and conflict-free navigation. In this experiment works, the control system is evaluated separately in each criteria listed as the following.

- Experiment of line detection.
- Experiment of sign detection.
- Experiment of obstacle detection.
- Experiment of conflict-free navigation

A. Line Detection Algorithm Experimental Result

Several different experiments are carried out to evaluate line detection algorithm. Firstly, the accuracy of navigation along straight line without any obstacle is given in three different velocities. Secondly, the accuracy of navigation along a curve line without any obstacle is given. Thirdly, the navigation capability to return to its original guideline during navigation process. Fourthly, the navigation capability to follow the original navigational path if there is other line adjoined. Finally, the navigation capability on the damaged straight line.

The experiment which has been explained previously is to test line detection algorithm and it has been implemented successfully. The results of an experiment are shown in Fig. 7. Vertical axis is a column pixels coordinate that displays a value of column center point of the guideline of any processed image. Meanwhile, horizontal axis is a number of images that have been processed throughout the experiments. A straight flat line indicates a value of column center point of the guideline that must be followed by the V-AGV. This center point value is fixed at the column pixels position of 163, based on an alignment and positioning of the USB camera that been fitted on the V-AGV platform. If in any particular frame image, this column center point is positioned at the column 163, it means that the V-AGV is moving and on his actual path. Any difference exists between a center line point and a column pixels coordinate in each image frame indicates there is a distance error. This distance error can be translated into an actual distance by using Equation (4).
successfully implemented. Table 1 shows the summary of an average of a distance error that has been achieved. There is a great performance on straight line navigation with a distance error does not exceeding 1.0 cm.

Table 1. Navigation Error for line detection algorithm tested under different navigation path design.

<table>
<thead>
<tr>
<th>Experiment No.</th>
<th>Navigation path</th>
<th>Error in cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Follow straight line</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>Follow the curve line</td>
<td>2.7</td>
</tr>
<tr>
<td>3 and 4</td>
<td>Staying in the real line</td>
<td>0.6</td>
</tr>
<tr>
<td>5</td>
<td>Broken line</td>
<td>0.9</td>
</tr>
</tbody>
</table>

B. Sign Detection Algorithm Experimental Result

The ability of autonomous navigations based on sign provided on side line is experimented. Sign detection by using area center of two regions has been tested.

Fig. 8 indicates a sample image result acquired after sign detection process. It can be noticed that, the orientation of the sign does not affect the result of sign recognition. The number 6 that been displayed on a image shows that a right sign has been identified, after applied sign detection algorithm which explain in section II.D. The percentage of detection failure is only about 15%. This failure mainly due to improper light setting condition, in which while V-AGV entering it path and navigating in a very high speed.

C. Obstacle Detection Experimental Result

In this experiment, the effectiveness of the proposed obstacle detection algorithm is tested and evaluated by placing several obstacles objects that have different sizes, color, shapes and materials on the guideline. The system is tested by placing several objects on a guideline until partially covered or fully covered from visible by a camera. Among the objects used are, dust bin, newspaper, books and boxes. Some of that obstacle, such as newspaper is bright and colorful, thus it is useful for a system to test that condition. The system will succeed to locate an obstacle presence and then will stop to avoid collision. Fig. 9 shows the experimental results on the obstacle detection algorithm.

D. Conflict-free Navigation Experimental Result

A conflict-free navigation is a special navigation of the V-AGV. It is needed to avoid some bottle-neck during AGV navigation. The experiment that has been conducted for that purposes, has shown that a system be able to stop, determine a size of an obstacle, generate path of a conflict-free navigation and then resume it journey in the original navigational path. The conflict-free navigation capability is a special feature of the V-AGV using a single USB camera. Fig. 10 shows the actual photos of the V-AGV navigates under the conflict-free navigation execution. The experimental results show that the proposed system has the capability to stop, generate path and control their navigation. The details explanations of this process are as below;

Fig. 10(a) When the obstacle is detected, the V-AGV platform will stop, reverse a bit and then calculate the width of obstacle and develop a path of conflict-free navigation.

Fig. 10(b) It will decide to choose a left path of conflict-free navigation. A platform will turn left. From now on and afterwards, the V-AGV will move without guideline.

Fig. 10(c) It will move forward.

Fig. 10(d) Then turn in an opposite direction in Fig. 10(b).

Fig. 10(e) Then continue move forward.

Fig. 10(f) Then turn in same direction as in Fig. 10(d). If the V-AGV camera is detected that still there is an obstacle in front, a system will generate an additional navigation path.

Fig. 10(g) In this experiment, the V-AGV has located a presence of a guideline. There are no more obstacles and the conflict-free navigation path has finished at this step.

Fig. 10(h) A V-AGV will return to the main navigation based on a guideline it has managed to locate.
The critical step in the process of avoiding obstacle on the floor is to estimate the width of the obstacle. A part from that, there are two possibilities in the generation navigation path while conflict-free navigation, either through right side of obstacle (see Fig. 11(a)) or left side (see Fig. 11(b)). From the experiment shown, when obstacle placed more to left side of guideline, system can choose right side. This is because found more big space in right side of guideline. On the other hand, if same obstacle placed more to right side above guideline, we found that the system successful choose left path in the guideline. The conflict-free navigation cannot be execute if the width size of obstacle could not are decided by vision system.

IV. CONCLUSION

The experimental results have shown that, the V-AGV navigation control systems have been successfully implemented on the real guideline system and platform in the laboratory environment. The vision based line following navigation for the V-AGV worked perfectly using a low cost USB camera. The proposed line detection algorithm, which consists of five regions, also functioned tremendously very well in the straight and broken line. This control system also has the ability to recognize a crossing line and the circle directional arrow floor sign to guide the V-AGV. The control system does not require their destination target to be programmed, it totally depends on the signs that been placed on the place, close the guideline. The obstacle avoidance be able to avoid any obstacle and continues it navigation simply relies on a single sensor.

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