Development of a Navigation System for an Autonomous Guided Vehicles

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Abstract - The automation of transportation in the production, trade and service sector is a key point in the optimization of intralogistics. For this task automated guided vehicle systems (AGVS) provide special benefits. Main points of these systems are the centrally controlled automated guided vehicles (AGV). In the beginning, the vehicles were guided by optical or inductive guidelines. The main disadvantages of guidelines are the inflexibility concerning the modification and changing of the routing and the necessity of installations on or in the ground. The group consisted of two robotic vehicles that were capable of carrying certain workpieces and supplying these to a predefined unloading location. These robots were microcontroller operated and were reprogrammable to accommodate the possible changes those in real industrial environment. Test runs were performed by programming these for maneuvering through both linear and curved trajectories. An imaginary industrial environment was prepared in the laboratory and the robots went through several successful test runs that validated the effectiveness of the prototypes. The research highlights the possibility of AGVs for the logistics purposes at reasonable cost using appropriate technology.

Index Term— industrial logistics, automated guided vehicles, appropriate technology.

I. INTRODUCTION

AGV (Automated Guided Vehicle) robots are widely used to autonomously transport workpieces between various assembly stations by following special guidewires or colored strips. Some AGVs transport food and medication throughout hospitals by tracking the position ceiling lights, which are manually specified beforehand to the robot. Some specialized robots take advantage of the regular geometric pattern of the office-spaces, supermarkets, warehouses, container terminals or even air-conditioning ducts [1-3]. In potentially dangerous and inhospitable environments, autonomous robots are gaining widespread popularity. Schulze and Zhao (2007) reported the widespread usage of AGVS in Europe and China [4]. For the developing countries, industrial applications of robots are not very popular and cheap labor cost plays an important role for such situation. However, when the production speed and accuracy are not to be sacrificed, application of automation employing robots offers a practical solution [5].

Although mobile robots have a broad set of applications, there is one fact that is true of virtually every successful mobile robot: its design involves the integration of many different bodies of knowledge and the design and construction of mobile robots is as much an art as a science. Robots locomotion actuators, manipulators, control systems, sensor suits, efficient power supplies, well-engineered software – all of these subsystems have to be designed to fit together into an appropriate package suitable for carrying out robot's task effectively, efficiently and safely [6].

To assess the possibility of design and fabrication of AGVs in Bangladesh - a developing country in South Asia, a group of robotic vehicles were developed and tested for effectiveness. In most stages of the prototype development, the application of appropriate technology and locally available raw materials and hardware components were considered to reduce the cost within permissible range for the local industries. The robots were made for picking up and delivering loads in predefined locations. The initial prototypes were designed to handle much lighter loads than most industrial applications. The loads pick-up and delivery was planned such that there were interactions between the two AGVs. One of the robots (C-Bot) was capable of gripping a cylindrical load and delivering it to another robot (Tray-Bot). Tray-Bot's wheels rear were fixed to a single shaft so that it could follow a straight path whereas C-Bot had two rear wheels separately powered and controlled and the controller generated control actions based on the readings from optical encoders attached to the wheels. Baglivo et al. (2005) used such encoders on the driver wheels of their AGVs [7]. Both the robots included tactile sensors – for Tray-Bot these were provided to sense the unloading destination – for C-Bot these were used as a safety in case of a collision with Tray-Bot. The linear trajectory of Tray-Bot and the curved trajectory of C-Bot were achieved by repeated test runs on the test field and updating the controller actions based on experimental results.

II. DESIGN AND IMPLIMENTATION OF V-AGV

The Automated Guided Vehicle or Automatic Guided Vehicle (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 has 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 VAGV system [8]. 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 [9]. 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.

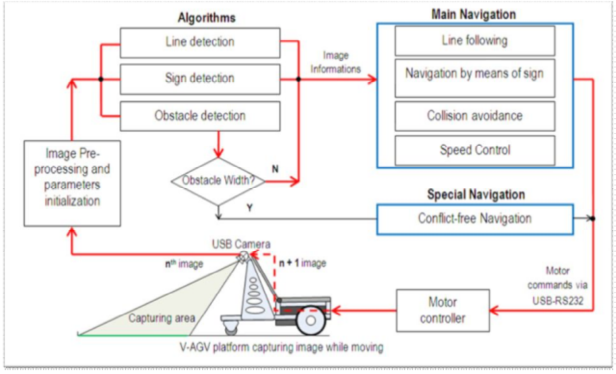

Figure 1. The model of V-AGV navigation and obstacle avoidance control system.

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 [10].

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 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 subs 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 ((Distance(n)[j] >= Minimum width of guideline and Distance(n)[j] < Maximum width of guideline and Edge amplitude of the edge [j]<0 and Edge amplitude of the edge [j+1]>0)

so

$S_{x,y}$(n)=[RowEdge, ColumnEdge[j+1]-(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 [0,0,1,1,1], 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 makes 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 [11].

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)*

Internal symbol External shape

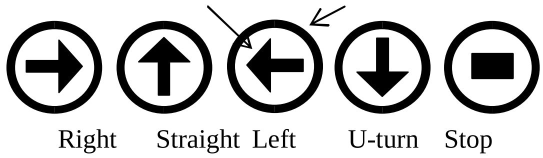

Figure 2. The directional arrow signs and stop sign.

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, Δ_{drow} and horizontal distance, $\Delta_{dcolumn}$ between two points; as shown in Fig. 3. Each distance is defined as follow;

Δ_{drow} = |rowcircle – rowsymbol|

$\Delta_{dcolumn}$.= |columncircle – columnsymbol|.

There are four possibilities;

{ Δdcolumn > Δdrow and Δdrow < Δdcolumn }, means directional arrow sign to left.

{ Δdcolumn < Δdrow and Δdrow < Δdcolumn }, means directional arrow sign to right.

{ Δdcolumn > Δdrow and Δdrow > Δdcolumn }, means directional arrow sign to straight forward. .

{ Δdcolumn > Δdrow and Δdrow > Δdcolumn }, means directional arrow sign to return back.

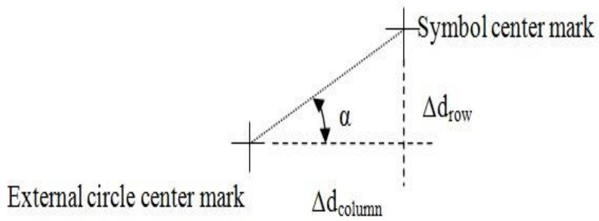

Figure 3. Center area of circle and symbol of sign.

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.

- l_{min} = Minimum distance on real coordinate can be captured is equal to 22.0 cm from camera position.
- l_{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
- α_1 = tan (h/ l_{min}) = 56.0 degree, this angle is depending with camera orientation and high position. Camera orientation is fixed.
- $\Theta_1 = 90^o - \alpha_1$ = 34.0 degree
- $\Theta_3 = \tan^{-1}(h/ l_{max})$ = 24.9 degree
- $\Theta_2 = P_y/S_y \times (90^o - \Theta_1 - \Theta_3)$
- P_y = 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

F. Conflict-Free Navigation Algorithm

Since there is a limitation on the structure of cable guide, th AGV cannot overtake or escape an obstacle. The AGV system is suffered of the bottleneck problem. If there is an obstacle or a breakdown AGV, the whole system has to be stopped. Therefore, a conflict-free navigation based on vision has been proposed to overcome that problem. Conflict-free navigation is a different form of navigation since it intent to generate new path in order to avoid obstacle and then return to the original guideline [12]. When this navigation is been executed, the V-AGV no more depends on the available guideline. It will find another safe path, without relying on a guideline and then return to the original path. Thus, a conflict-free navigation can be divided into three parts;

- Path Generation,
- Control, and
- Resuming the original guideline.

After an obstacle been traced, including it characteristics such as width, distance and type of obstacle, a conflict free path will be generated, as shown in Fig. 6. In order to get a proper path, several parameters to been used need to be defined. They are as follows:

- Obstacle width,w
- Path offset, Δw
- Maximum path offset allowed, Δwmax
- Distance between two wheels, R
- Radius of wheels, r
- V-AGV length, L
- First rotation angle, ϴ(t1)
- Second rotation angle, ϴ(t2)
- Initial translation distance, li
- Maximum translation distance, lmax
- Final translation distance, lii

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, ϴ(t1) 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, ϴ(t2) happens at the point b, c and d.

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.

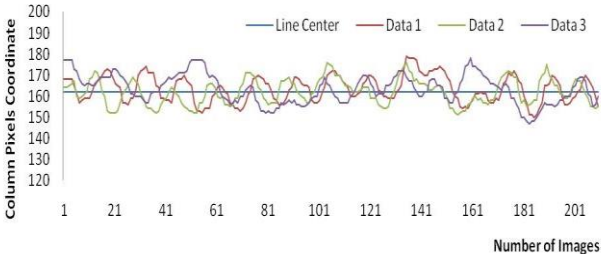

Figure 4. Accuracy of the line following navigation.

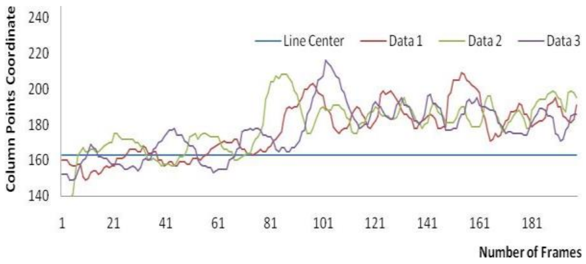

Figure 5. Accuracy of the navigation following a curve line.

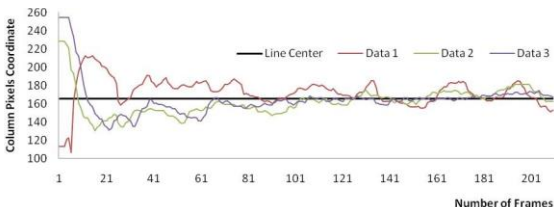

Figure 6. The capability to return to the navigational path

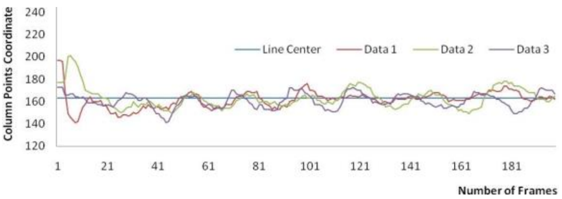

Figure 7. The capability to follow the original navigational path.

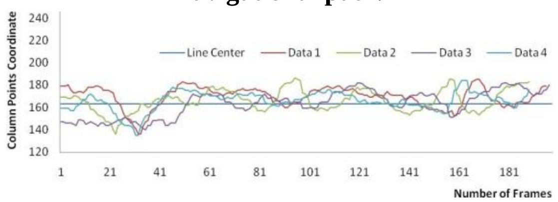

Figure 8. The capability to follow the broken navigational path.

From all of the experiments that have been conducted, it can be noticed that a line detection algorithm have been 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.

Experiment No.	Navigation path	Error in cm
1	Follow straight line	0.5
2	Follow the curve line	2.7
3 and 4	Staying in the real line	0.6
5	Broken line	0.9

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. 9 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.

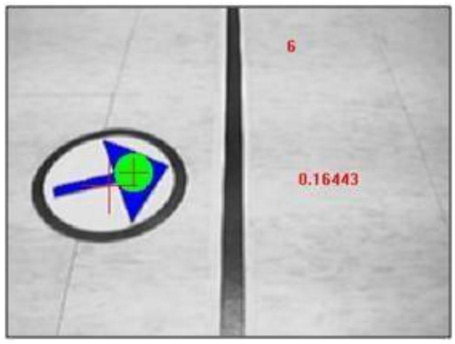

Figure 9. The sign detection and recognition experimental results.

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 colourful, 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. 10 shows the experimental results on the obstacle detection algorithm.

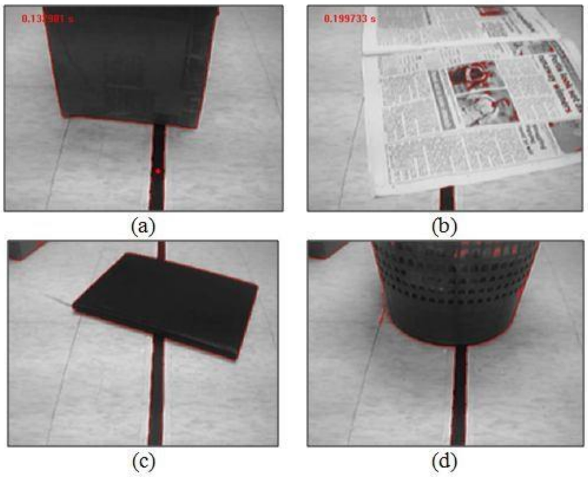

Figure 10. Different types of obstacles used in the experiment.

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 VAGV 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. 11(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. 11(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. 11(c)	It will move forward.
Fig. 11(d)	Then turn in an opposite direction in Fig. 10(b).
Fig. 11(e)	Then continue move forward.
Fig. 11(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. 11(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. 11(h)	A V-AGV will return to the main navigation based on a guideline it has managed to locate.

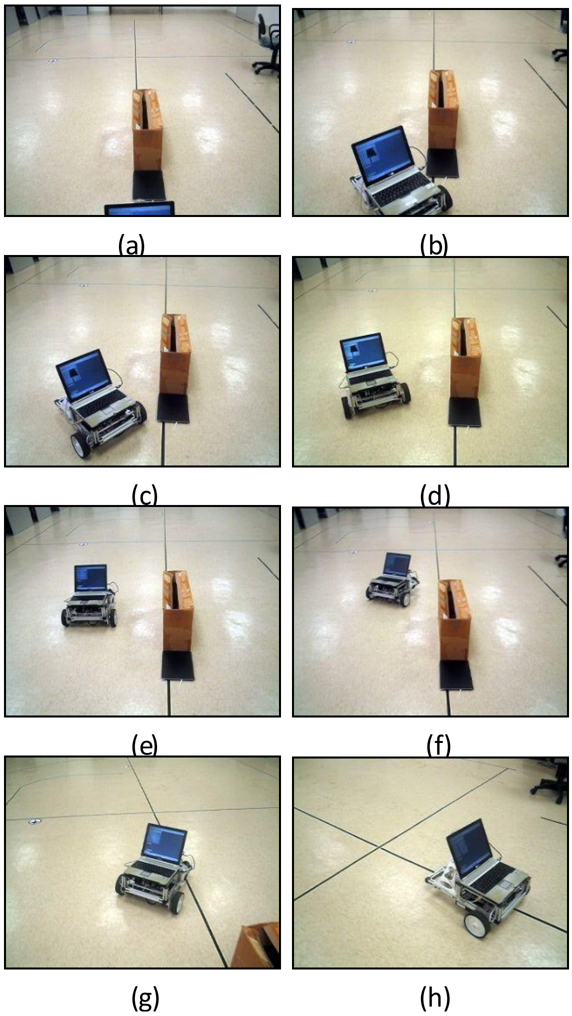

Figure 11. The sequence of steps executed during experiment under the conflict-free navigation conditions.

The critical step in the process of avoiding obstacle on the floor is to estimate the width of the obstacle. A parts from that, there are two possibilities in the generation navigation path while conflict-free navigation, either through right side of obstacle (see Fig. 12(a)) or left side (see Fig. 12(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.

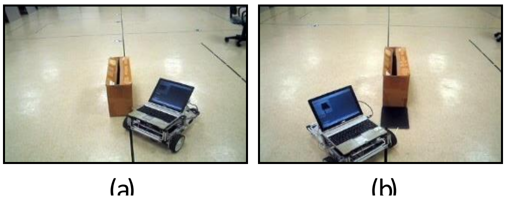

Figure 12. A path generation in the conflict-free navigation.

IV. CONCLUSION

In the perspective of a developing country working with sophisticated technologies is a challenge. A frustrating situation occurs when one or more key components for a design are not locally available. Searching for components from foreign companies may incur a huge amount of investment of money and time which may act as a repelling force for the interested local industries. The AGVs prototype development was performed with the limited resources but in case of mass production of such systems, some of the necessary key components could be imported. In this case, the cost of the components could be minimized by the large amount of supply.

The robots developed in this research were lightweight and in some cases, slow speed. These could be modified and improved easily to meet the industry demands. From the test runs, it can be recommended that the usage of tactile sensors should be replaced by proximity sensors whenever possible as these sensors have lower expected life. Finally, it is worthwhile to mention that the possibility of AGVs development has a bright future in Bangladesh and the industries should come forward instead of becoming too much dependent on expected technology.

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