Closed-Loop Systems of Line Follower Robot Using Camera Vision

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Abstract—**Computer vision of robotic applications has given a lot of benefits to robotic advancement. This study aims to design a robot that can follow a dark line path using a camera vision. A vision-based is a new technology that uses an image processing technique instead of using a sensor. An effective closed-loop control system is used to overcome the robot's problems, moving out from the track by using a line searching mechanism. This project used NI-myRIO as an embedded platform for image processing and robot motion. The NI-myRIO is connected to LabVIEW on PC wirelessly for broader processing capability while providing maximum mobility to the robot to move freely on the designated track. Aiming for the guided line to always be at the center of the region viewing window, each tire's speed on the left and right part of the mobile robot is controlled accordingly. The result shows that using a line searching algorithm with a camera vision line follower robot improves an overall mobile robot performance to follow the line without failure with faster speed.**

Keywords—Robot vision; Line follower robot; Line searching

I. INTRODUCTION

ROBOTICS development and application using camera vision has accomplished its extreme achievement in the world of manufacturing and other fields of application such as precision agriculture, healthcare and construction [1]–[4]. A line follower robot is mostly a robot designed to follow a line or path already fixed by the user. This line or path may be as modest as a physical black line on the white surface [5], [6] or as complex path marking structures, for example, embedded lines, and it also can be unseen like a magnetic field [7], [8]. Various sensing schemes can detect these specific markers or 'lines'. These schemes may vary from simple, low-cost line sensing circuits or moderate vision systems [9]. These schemes' choices would depend upon the sensing accuracy and flexibility required.

From the industrial point of view, the line following robot has been implemented in semi to fully autonomous because the robot can replace a human's job in the industry and can do many things faster than humans [10]. Robots do not need to be paid for their work; they can do tedious work that is boring to people, and they will not stop, slow down, or fall asleep like a human. Individual stationary sensors have limited ranges and applications.

Robotic site security sentries can work long hours at a consistently high level of precision and vigilance [11]. In this environment, these robots function as materials carriers to deliver products from one manufacturing point to another where rail, conveyor and gantry solutions are impossible. Apart from the line following capabilities, these robots should also be able to navigate junctions and decide which junction to turn and which junction to ignore. This situation would require the robot to have 90-degree turn and junction counting capabilities.

Line following robots with pick and placement capabilities is commonly used in an industrial unit [12]. These move on a specified path to pick the components from specified locations and place them in desired locations. In precision agriculture, such a robot with vision capability might be able to do the fruit picking task or de-weeding the plant's medium [13]. A line following robot is a self-operating robot that detects and follows a line drawn on the floor. A black line indicates the path to be taken on a white surface. The control system must detect the line and ensure the robot stays on course while correcting the wrong moves. In this study, the development of a vision-based line follower robot using NI-myRIO is demonstrated to replace the traditional method of using passive infrared (PIR) sensor previously done in [5], [14].

The line searching mechanism is chosen to prevent the robot from moving out from the track. Thus, the robot moves more accurately with good velocity on its track. On the other hand, another feature like an obstacle detection system has been introduced to prevent users from hitting any objects facing the robot on its track. This navigation system is also used to navigate the robot back to the track in case the robot gets out from the track.

This manuscript consists of four major sections, including this section. The following section is the methodology. In that section, the development process of the line following robot is explained in detail. Section III focuses on the result and discussion; the last section is the conclusion.

II. METHODOLOGY

Robot development is divided into two-part; the first part is the development of robot structure, wiring and I/O configuration for basic robotic functions such as robot mobility and motion. The second part is the development of lines following an algorithm, including line detection and decision making.

The development of robot structure emphasises the robot's stability in motion to avoid the robot from falling while moving around. Following algorithm development, the camera's image stream is pre-processed on the line to determine whether the current position and robot

direction are toward the centre of the detected line. The block diagram in LabVIEW was developed, and a line following program was created using the line searching mechanism programmed in NI-myRIO.

A. Development of Line Follower Robot Structure
In this stage, the line follower system for the robot is developed. This stage includes a line follower's basic structure and working principle using NI-myRIO as the main controller.
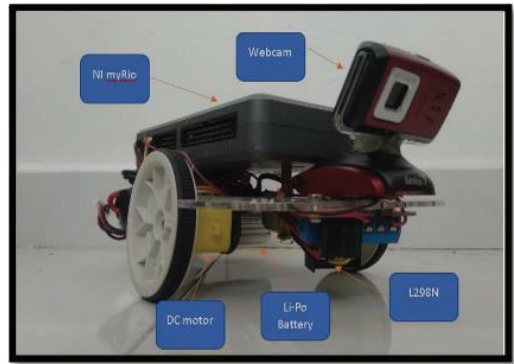

Fig 1: Working prototype of the line follower robot

The line follower system in this mobile system is guided by a webcam to follow the track line. The webcam is placed at the centre top of the robot so that it can capture and detect the black line more precise and clearer. Figure 1 shows the prototype of the line follower robot.

B. Development of Line Following Robot Algorithm
The communication between NI-MyRIO embedded device and LabVIEW software on the PC is through a Wi-Fi connection where the programming of the mobile robot is taking place on both the PC and the embedded device. A few Virtual Instruments (VI)s blocks were used in the line detecting system development, such as the 'IMAQdx Open Camera VI' 'IMAQdx Configure Acquisition VI', 'IMAQdx Start Acquisition VI', and 'IMAQdx Stop Acquisition VI'. Figure 3 shows the block diagram to display an image captured from a webcam on a GUI display.
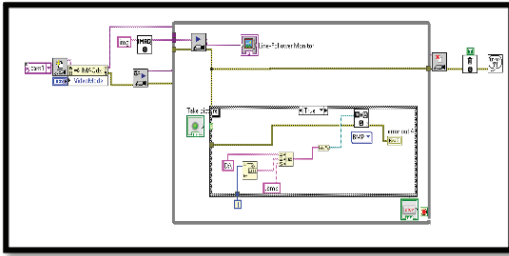
Fig 3: Block diagram to display the image captured by the webcam

Table 1: The function of basic Vision and Motion Block Vis

IMAQdx VI	Function
IMAQdx Open Camera VI	Open the camera, queries the camera for its capabilities, load a camera configuration file and create a unique reference to the camera.
IMAQdx Cinfigure Acquisition VI	Configure a low-level acquisition previously opened with IMAQdx Open Camera VI. Specify the acquisition type with the 'Continuous' and number of buffers' parameters.
IMAQdx Start Acquisition VI	Starts an acquisition that was previously configured with the IMAQdx Configure Acquisition VI.
IMAQdx Stop Acquisition VI	Stops an acquisition previously started with the IMAQdx Start Acquisition VI.

The brief information on the Vision and Motions Block VIs from LabVIEW is shown in Table 1. Each of the VIs plays an important role in the line detecting system. Some image filtering VIs are added to the system circuit to improve the captured image quality.

In this study, the additional filter VI of 'IMAQ Threshold', 'IMAQ Overlay Rectangle', 'IMAQ Extract Single Color Plane' and 'IMAQ

Particle Filter' are being implemented into the line detecting block circuit. Table 2 shows the function of filter blocks.

The output image from the 'IMAQdx Extract Single Color Planes' is connected to the 'Image Src' terminal of 'IMAQdx Threshold' to replace the value of the pixels existing in the range between lower value and upper value. The upper and lower values are fixed in this project, from 0 to 93. 'Image Out' terminal of 'IMAQdx Threshold' are connected to the 'image' terminal of 'IMAQdx Overlay Rectangle' for specifies the coordinates of the rectangle to overlay and have drawing mode such as specifies whether to draw only the frame of the rectangle, fill in the rectangle, or highlight the rectangle. Figure 4 shows the connection between the 'IMAQ Threshold' and 'IMAQdx Overlay Rectangle' block.

Table 2: The function of filtering VIs

IMAQ Block VI	Function
IMAQ Threshold	Determine whether to replace the value of the pixels existing in the range between lower value (default is 128) and upper value (default is 225)
IMAQ Overlay Rectangle	Specifies the group to which one wants to add the overlay information. If no name is specified, the overlay information is added to the default group. It also specifies the coordinates of the rectangle to overlay on the image.
IMAQ Extract Single Colour Plane	Take outs selected planes colour models like RGB (red, green, blue), HSL (hue, saturation, lightness), HSV (hue, saturation, value) or HSI (hue, saturation, intensity) from an image
IMAQ Particle Filter	Define the Region of Interest (RoI)within which particle filter is performed and contain the coordinate of the bounding rectangle to indicate the contour's relative position.

After the rectangular size has been selected, the output image of 'IMAQdx Overlay Rectangle' will pass through the image to the 'IMAQ Particle Filter' block. When an image is processed through 'IMAQ Particle Filter', the output is masked, and only the Region of Interest (ROI) from the image is displayed with all the other particles of the image blackened out. The input image of the 'IMAQ Particle Analysis' is connected to the output image of the 'IMAQ Particle Filter'; this block will return the number of particles detected in a binary image and a 2D array of requested measurements about the particle. Figure 5 shows the connection between 'IMAQ Particle Filter' and 'IMAQ Particle Analysis'.
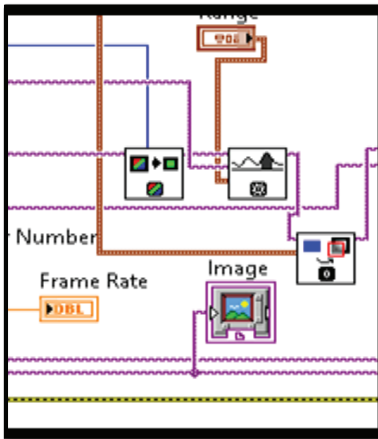

Fig 4: Connection of the 'IMAQ Threshold' and 'IMAQdx Overlay Rectangle'

The output session of 'IMAQdx Start Acquisition' is connected to the input session of 'IMAQdx Stop Acquisition' to stop an acquisition previously started with the 'IMAQdx Start Acquisition'. Next, the output session of 'IMAQdx Stop Acquisition' has been connected to the input session of 'IMAQdx Close Camera' to stop an acquisition in progress, releases resources associated with an acquisition, and closes the specified Camera Session. Then, the output image of 'IMAQdx Get Image' has been connected to 'IMAQdx Dispose Vi' to destroy an image and free the space it occupies in memory. Execute IMAQ Dispose only when the image is no longer needed in your application. You

can use IMAQ Dispose for each call to IMAQ Create or just once for all images created with IMAQ Create. Figure 6 shows the connection between 'IMAQdx Stop Acquisition', 'IMAQdx Close Camera' and 'IMAQdx Dispose Vi'. Figure 7 shows the Overall Block Diagram of the Line Detection System.
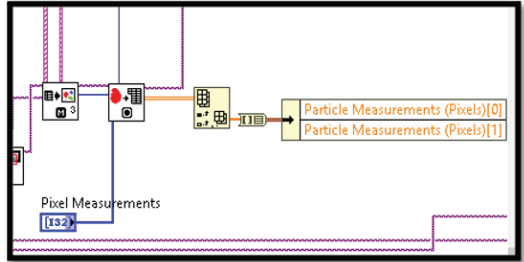

Fig 5: Connection between 'IMAQ Particle Filter' and 'IMAQ Particle Analysis'
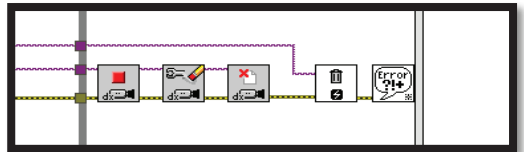

Fig 6: Connection between 'IMAQdx Stop Acquisition', 'IMAQdx Close Camera' and 'IMAQdx Dispose VI'
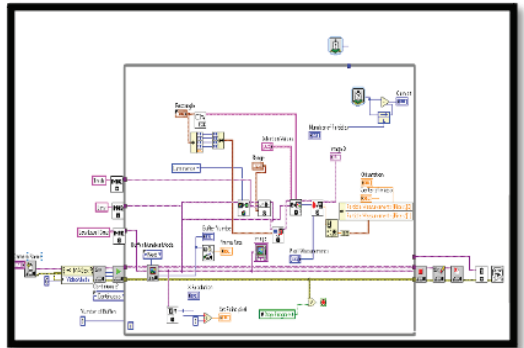

Fig 7: Overall Block Diagram of the Line Detection System

A robot movement system has been developed to navigate the robot whenever the line follower robot detects a line on its path. This movement system has been created using LabVIEW software. Users can also manually control the robot's direction, such as 'Left', 'Right', 'Forward' and 'Backward'. Figure 8 shows the manual navigator of the line follower robot.
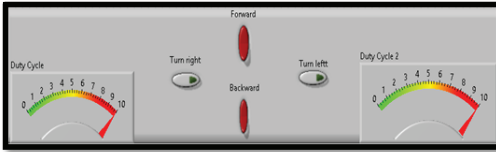
Fig 8: The Manual Navigator of Line Follower Robot

Table 3: Pin Connection between NI-myRIO and L298N Driver

	NI-myRIO	L298N Driver
Analogue Pins	A1	PWM 0 (pin 27)
	A2	PWM 1 (pin 29)
Digital Pins	B1	DIO 6 (pin 23)
	B2	DIO 7 (pin 25)

L298N H bridge is used as a driver to control the speed of the DC motor. Four pins have been used to connect NI myRIO and the L298N driver. Two analogue pins have been used to control the Right Motor direction and the Left Motor direction. Analog pin help to generate a pulse width modulation (PWM) signal to an external peripheral through the PWM channels and change the duty cycle. Then, two digital pins are used to do the manual navigation, such as turning on or off the DC motor. Table 3 shows the connections between the NI-myRIO and the L298N driver.

The block diagram has been designed based on the centre of mass x. The camera will detect the line based on the range provided. The centre of mass x is the centre of the rectangle box; this rectangle box will show the detected line coordinate. A program has been designed in the centre of mass x in between 170 to 200, left and right dc motors will rotate clockwise so the mobile robot will be moved forward. The suitable DC motor will rotate clockwise whenever the centre of mass x coordinates between 201 to 500, so the mobile robot will turn left when the centre mass coordinate between 1 to 69, and the left dc motor will rotate clockwise so that the mobile robot will turn right. Thus, if the centre of mass is 0, the dc motor will stop. Figure 10 shows the overall front panel of the vision line following the robot.

III. RESULT AND ANALYSIS

A. Line Following Performance

The overall testing result of the prototype robot was satisfactory, especially when it was being tested in a straight line. In the LabVIEW block diagram, the wheel mode of the dc motor is set to the maximum speed, which is 0.5 duty cycle. When the prototype robot senses the corner path, the robot is programmed to have one wheel slowed down to half the original speed to ensure smooth turning.

However, during the preparation of the line path, one corner of the loop path is purposely designed to have a sharper corner to observe the robot's reaction. As a result, the camera missed detecting the line at the designed sharp corner. The robot's moving speed could not match the supposed turning speed. Before the robot can finish a turn, it is already off-tracked and leads to zero output coordinate of line detecting as it detects no line.

B. Line Searching Mechanism

The line searching mechanism is a method used to prevent the line follower robot from moving out from the line. Using the camera for the detect line is a huge difference from using an infrared sensor because the camera provides a wide angle of vision, so it will easily move out from its path. The line searching mechanism will help the line follower robot to find its track by finding the nearest line available. This method is applied to the line following robot because it provides more advantages than the previous method, such as overcoming the problem faced by all line following robots, which quickly step out from their track [15], [16].

When the speed of the DC motor increases, it will affect the probability of a robot completing a lap. In this line follower robot project, the speed of the dc motor is controlled using pulse width modulation (PWM) by changing the duty cycle. An analysis has been done by comparing the time the mobile robot took to complete three laps with different speeds of DC motor.
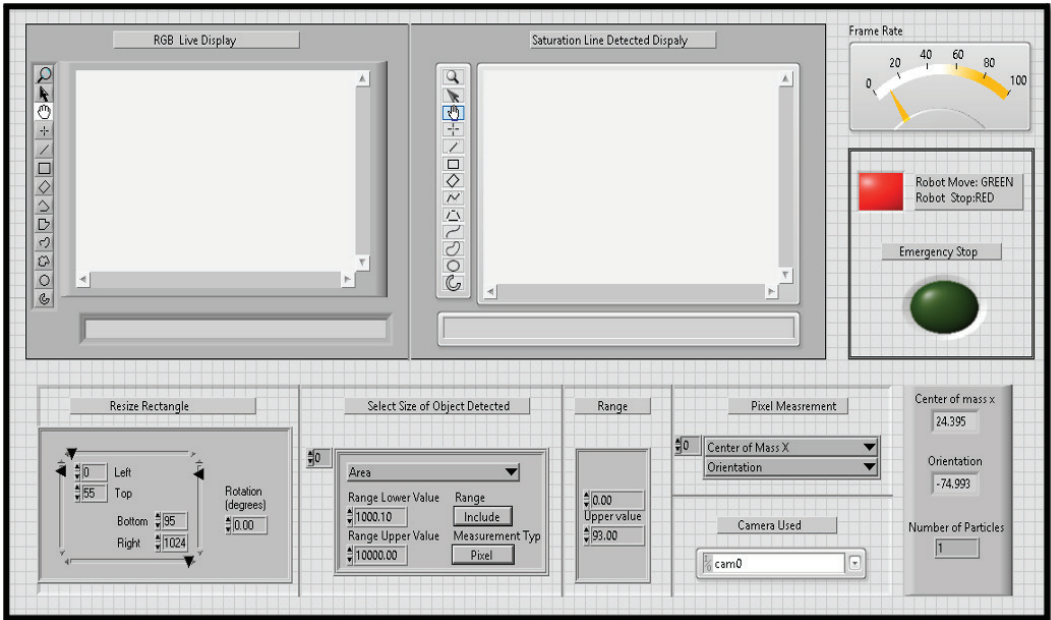
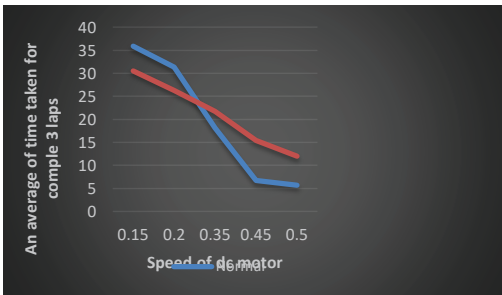Fig 10: Overall front panel of vision line following robot

Fig 12: The comparison between normal and line searching mechanism method

By comparing the normal (switching method) and line searching mechanism, we could say that the performance line searching mechanism is higher than the normal method. Figure 12 shows the comparison between the normal and line searching mechanism method. Based on Figure 12, the average time taken to complete three laps when the DC motor speed increased for the line searching mechanism is more stable than the normal line following robot. This setup proved that the line searching mechanism could prevent the line follower robot from moving out from the track. The line searching mechanism also produces more efficient motion and moves faster than the normal method. Thus, we could say that the line searching mechanism works well in the line following robot system.

IV. CONCLUSION

At the end of this project, a fully functional prototype of a line follower robot using a camera was successfully designed and constructed. Line follower robots are essential and vital, especially in industries, because they can help the worker carry the heavy load safely and more systematically. Besides that, the line follower robot also can reduce the number of hazards in industries caused while carrying heavy loads among workers. Line following robots is one of the methods that provide a safe environment.

By using a line searching mechanism, an effectual output has been obtained. From the analysis we identified, the line searching mechanism is the perfect method for a line follower robot to overcome a mobile robot from stepping out from its track.

This project concept can be further integrated into a stereo-vision system in the future because the stereo camera can help track or detect lines better

by providing a wider view. This configuration can prevent the mobile from moving out from the track because it cannot detect the line. Besides that, using the stereo-vision system can precisely detect lines, so the mobile robot can follow the line smoothly and accurately.

ACKNOWLEDGEMENT

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