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PROTOTYPE LINE FOLLOWING AUTOMATIC GUIDED VEHICLE (AGV) FOR UNIT LOAD DISPATCH IN AN OFFICE ENVIRONMENT

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ABSTRACT
Within the office environment, file dispatch from one desk to other by clerical officers is common place in the world particularly in countries where technology has not been critically deployed. This unskilled monotonous task should not necessarily be undertaken with the potential natural intelligent human beings. Human beings are created with natural intelligence; they can be trained to use this intelligence to handle skilled tasks like building a robot for instance. Therefore, this paper presents the development of a prototype line following AGV for unit load dispatch in an office environment. Although line following navigation technique is the cheapest in terms of installation cost. Nevertheless, appropriate sensor positioning to achieve effective tracking of curvy path is still a predominate challenge. This paper equally addresses this issue. Thus, presents the analysis for the evaluation of the critical entry angle of the AGV based on the IR sensor position. The AGV successfully traverse a unit load through the test path proving the effectiveness of the proposed method. Therefore, the AGV can replace the need for a clerical officer transferring mails between two point within an office environment. Whereas, the present work only considers material transport between two points, in the future we will like to consider material transport between several points within the office environment. This will require path flexibility which is not achievable with line following, thus, we will incorporate path planning and path tracking controller.

Keywords: AGV, Unit load, Material transport, line following, IR Sensor

INTRODUCTION

One of the monotonous tasks within manufacturing facility is material transport. Material transport is an integrated logistics activity involving efficient and effective transfer of materials between different locations with processing or storage intent (Gaur and Pawar, 2016; Deshpande *et al* ., 2017). Tauseef (2010) described the manual and elctromechical method applied in material transport. However, advancement in technology has lead to the development and application of Automatic Guided Vehicles (AGVs). Culler and Long (2016); Wan *et al* (2017) described the AGV as a class of wheeled mobile robot for material transport task, particularly in what Wan *et al* (2017) described as smart factories. AGVs are simply unmanned vehicles deployed for material transport within manufacturing facility (Luettel *et al*., 2012; Ilas, 2013; Kaliappan *et al* ., 2018). AGVs improves efficiency and reduce cost of material transport where they are applied (Kaliappan *et al* ., 2018; Wu *et al* ., 2017). The navigation system applied in AGV technology is the fixed path and free-range type (Sankari and Imtiaz, 2016; Lee and Chia, 2017). Fig 1 and 2 present types of AGV and some common navigation techniques employed in the mentioned navigation system respectively.

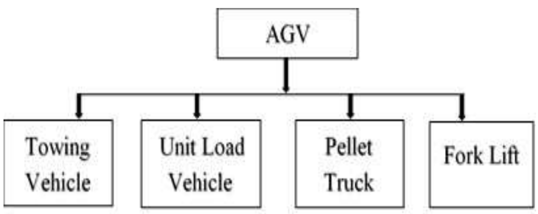

Fig. 1: Common AGV Types (Source: Lynch *et al* ., 2018)

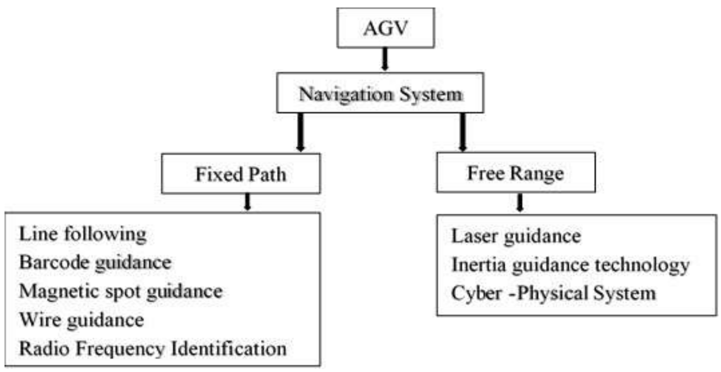

Fig. 2: Some Common AGV Navigation Techniques (Source: Bostelman *et al* ., 2015; Lee and Chia, 2017; Yin *et al* ., 2018)

Conventionally, AGVs are applied within manufacturing facility (Wu *et al* ., 2017), however, they have in recent times find application within other industry such as mail dispatch within the office environment (Chinchkhede and Shende, 2018) reducing human exertion through automated transport (Chowdhurya *et al* ., 2017). The unit load type of AGV are usually applied for such task; where the unit load can be files or a patient medication in office or hospital environment respectively (Kaliappan *et al* ., 2018). Within the office environment file dispatch from one desk to other by clerical officers is common place in the world particular in countries where technology has not been critically deployed. This unskilled monotonous task should not necessarily be undertaken with the potential natural intelligent human beings. Human beings are created with natural intelligence; they can be trained to use this intelligence to handle skilled tasks like building a robot for instance. Therefore, this paper presents the design of a prototype line following AGV for unit load dispatch in an office environment. Line following AGV can sense a line drawn on the floor using Infra-Red (IR) sensor (Pintu and Dubey, 2013) and follow this path (Elayaraja and Ramabalan, 2017). The line following navigation technique is the cheapest in terms of installation cost of all the listed techniques in Fig 2 according to Lynch *et al* (2018). Hence, it has found application in differs areas (Wu *et al* ., 2017). However, the unsuccessfulness of the AGV to follow curved path without veering off is a recurrent problem in literature (Saad *et al* ., 2018). Thus, this paper will be addressing the curved path following problem by appropriate sensor position evaluation.

RELATED WORK

In literature substantial number of works has been done on application of AGV with line following navigation techniques using different approaches for effective line following. Chinchkhede and Shende (2018) developed a theoretical model for unit load dispatch using AGV within an office environment. Kaliappan *et al* (2018) presented mechanical design concept AGV using NX 9 Modeling software and ANSYS R15 for analysis. Implementation of their design in the automobile industry presents reduction in material transport cost, production time and plant layout due to line following navigation technique. Chowdhurya *et al* (2017) addressed the issue of complexity of line following AGV by proposing algorithm to follow path with curves, T-junction, + junctions and 90 degree bend using four Infra-Red (IR) sensors. Each pair using different algorithm applied to different path scenario. Although the approach was effective, but AGV speed had to be reduced at the junctions and 90 degree bend in order to accurately follow the path. Elayaraja and Ramabalan (2017) investigated the effect of varring rear wheel diameter and distance between Castor wheel position and rear wheel (center to center distance) on the travel time of an AGV on a predefined 4 meter path. They applied the Design of Experiment (DOE) and fuzzy logic system approach for their investigation. The result show that with bigger rear wheel diameter and small center to center distance the AGV travelled the least time on the 4 meter path. Pintu and Dubey (2013) described a model for task sharing possibility between two AGVs following the same path. The AGVs were designed using P89V51RD2 microcontroller with different addresses. The AGVs intracts via IR sensor. Their approach is vital for industries with complex task which can be divided in subtask complete successively by separate AGVs. Saad *et al* (2018) described the development of a line follower AGV for surveillance application. For line tracking and wheel steering through binary control system four IR sensors were used. With Arduino Uno as main controller their result show that the AGV tracked the straight path accurately. But performed poorly on the curved path as it veers off-track due to the dissonance between the Arduino process speed and infrared sensor resolution. This further confirms the need for the precise positioning of the IR sensors for effectiveness (Chowdhurya *et al* ., 2017). Therefore, this paper presents the development of a prototype line follower AGV for unit load dispatch application in an office environment using apprpriate method for the IR sensor position evaluation. The delimitation of this work is that the AGV tracks a dark line path marked on a white surface. The dark line path is made using black tape on a white surface. The path and the surface are isolated from obstacles. Thus, obstacle detection is not considered in this work.

MATERIALS AND METHODS

The chassis and unit load carrier compartment were fabricated from 1 mm thick aluminum and Corrugated cardboards respectively. The Computer Aided Design (CAD) model of the chassis and the unit load carrier compartment are presented in Fig. 3 and 4. CAD is explained as the application of computer with appropriate software Autodesk Inventor for example for the process of part design and documentation. Furthermore, complex design can be achieved with greater precision and considerable effort (Adefemi *et al* ., 2018; Adekunle *et al* ., 2018))

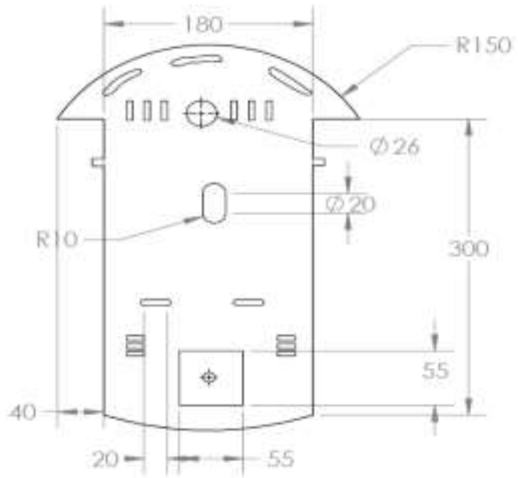

Fig. 3: AGV chassis (dimension in mm)

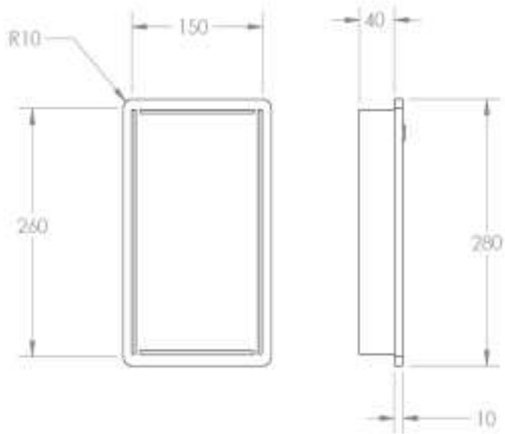

Fig. 4: Unit load carrier compartment (dimension in mm)

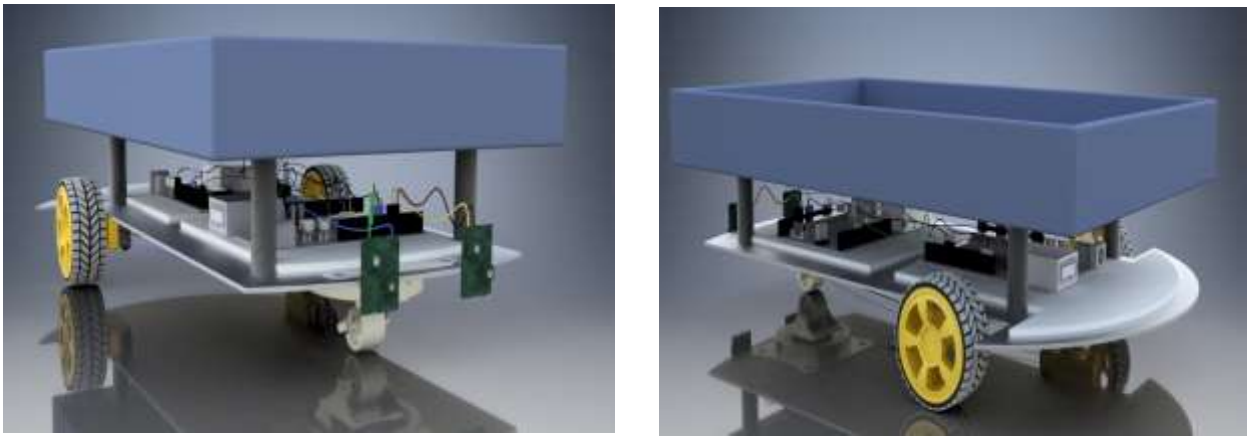
Fig. 5 :The AGV

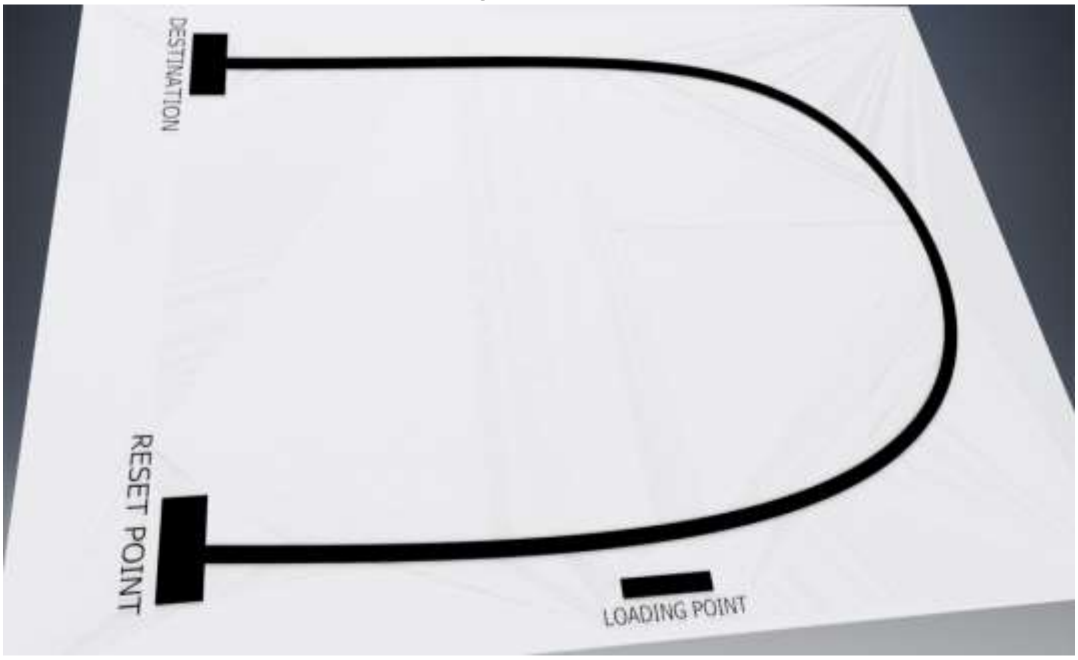

Fig. 6: AGV path

Table 1: Hardware component overview

S/N	Hardware	Qty.	Model/ Version	Description	Justification
1	Geared DC motors with fixed standard non-deformable traction wheels	2	TT motors	The geared DC motors drives the non-deformable traction wheels. These are the rear wheels.	Robot locomotion and speed to torque variation.
2	Un-motorized castor wheel	1	Generic	This is the third ground contact point at the front	Stability
3	Arduino board	1	UNO R3 Current: 45mA Operating voltage: 3.3V, 5V, 9V	It uses ATmega328 microcontroller. It has 14 digital input/output pins (6 can serve as PWM outputs), a 16 MHz crystal oscillator, an ICSP header and a reset button. The hardware is the programmable circuit board and the software is the Integrated Development Environment for coding on the computer. C++ was used for coding.	Automation of attached motor shield, geared DC motors and IR sensor,
4	Motor driver module	1	L293D driver Shield Current: 500mA Operating voltage: 4.5 – 6V	This is an L293D module for Arduino UNO MEGA2560 R3. It is a monolithic integrated high voltage, high current two channel driver.	The microcontroller cannot output the desired high current to drive the geared DC motor directly. Thus, the DC motors are connected to the microcontroller via the driver shield.
5	Infrared sensor module	3	Smart electronics IR sensor Current: (0.5mA = 1.5mA Voltage: 5V	This is a 3 pin IR infrared sensor module which consists of an opto-coupler (infrared LED and a photodiode).	IR sensor pair consist of two diodes. Similar to the transmitter and receiver arrangement in ultrasonic sensors. IR LED emits infrared radiation. This radiation illuminates the field of view of the of receiver LED. where the receiver receives the reflected ray, it is interpreted as a white surface and if it cannot receive it, it interprets a black surface. Thus, guiding the AGV along the path.
6	Push Button	1	COM-00097 micro switch	It is a momentary push button Switch.	This is for sensing the unit load in the unit load carrier.
7	LED	1	Green LED 10mA at 5V	This a green Light Emitting Diode	AGV status lamp. Illuminated when the AGV is moving and vice-versa.

8	DC- DC step up power converter module	1	DC-DC step MT 3608	It is an adjustable voltage regulator that helps to step up to the required voltage	This was used to maintain the output voltage at 5V by adjusting the potentiometer screw.
9	Micro USB Li-ion battery charger module	1	Micro USB 5V TP4056	It features a battery overcurrent protection capability with a micro USB input terminal to recharge the li-ion battery and still retain the input voltage.	Used to recharge the li-ion battery after long hours of operation.
10	Male to female jumper wires	36	Generic	It is a male to female jumper wire set with clips at both ends	This provides interconnectivity features between different components used.
11	Resistor	1	1 kΩ	It is a four-band colour code resistor (brown, black, red, gold)	This was used as a pull-up resistor to the push-button.
12	Motor bracket T-headset	2	TT-geared	Motor bracket T-headset	To fasten the DC motor to the base of the chassis
13	Battery Li-ion 3600 mAh	1	Li-ion	It is a two terminal lithium ion battery	Power source

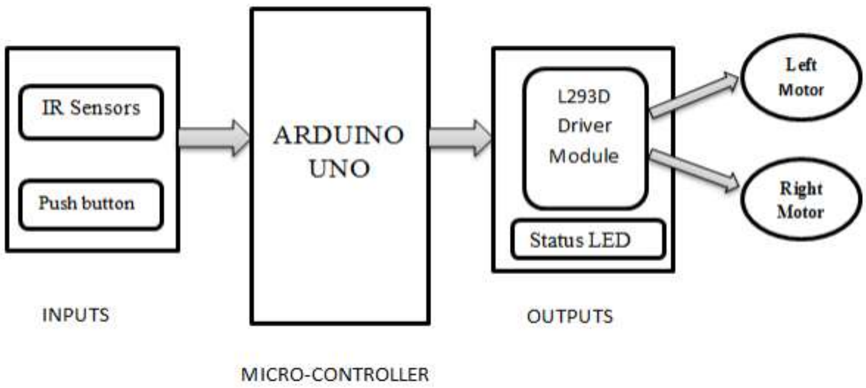

Figure 7 AGV block diagram

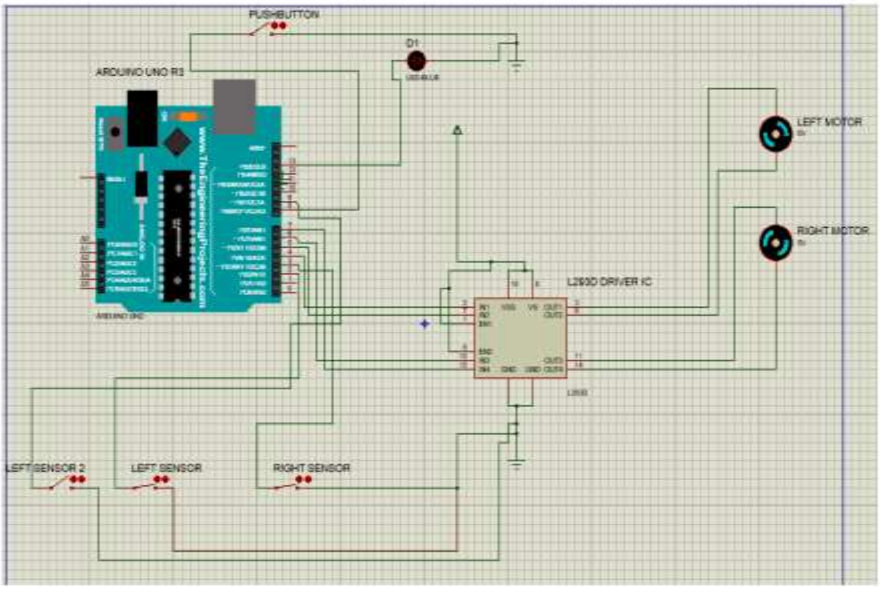

Figure 8 Circuit diagram

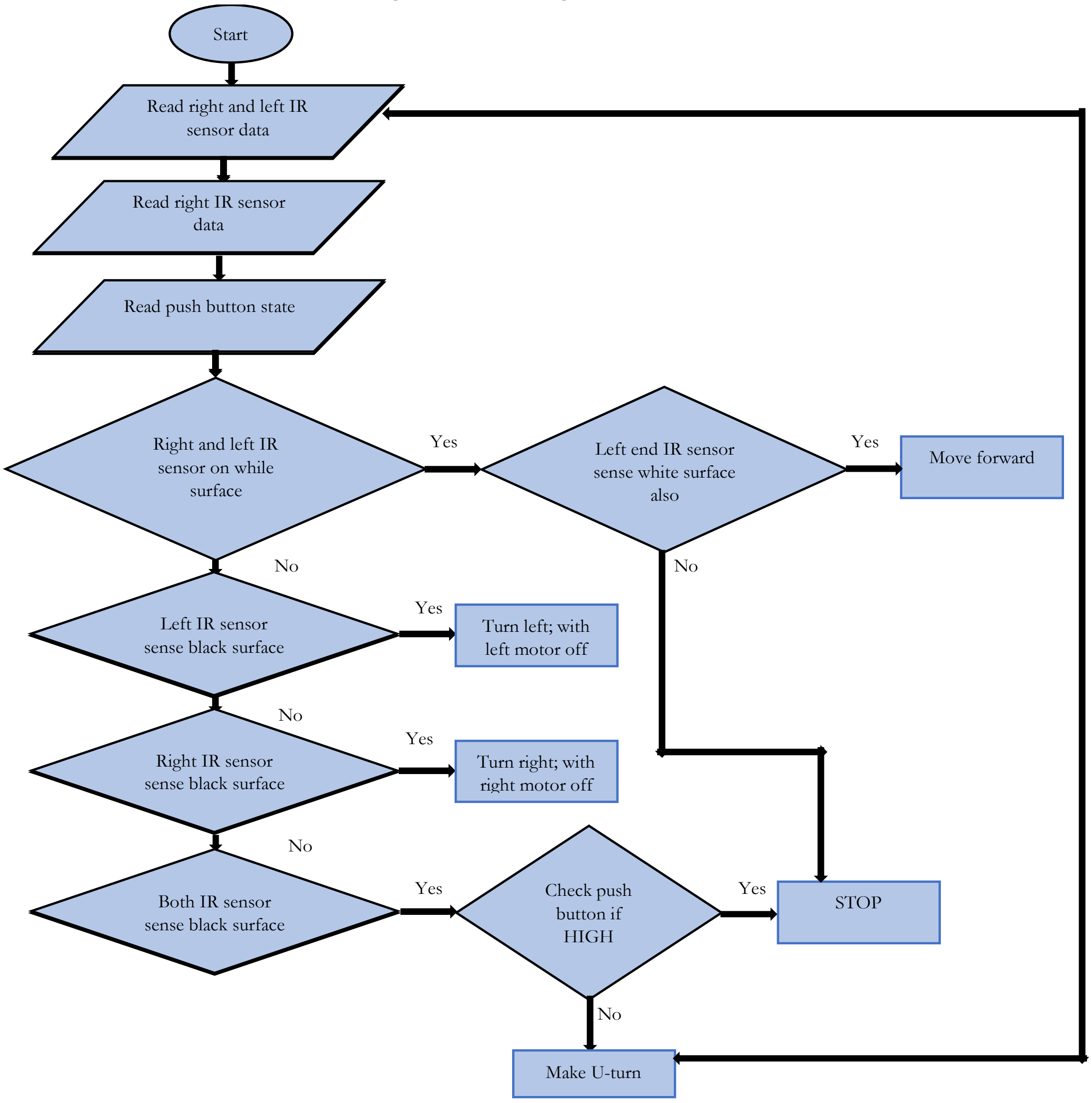

Fig. 9: Flowchart of the process

RESULTS AND DISCUSSION

The test path consists of straight and curvy path as shown in Fig. 10 with the loading point, reset point and destination point. The AGV traverse this path autonomously and uses information received from the environment to adjust itself accordingly. The cycle of the AGV starts from the loading point. Where a unit load will be place on the AGV. Then it begins to follow the dark line to the destination point. At the destination point the AGV waits until the unit load is offloaded. While the AGV is in motion the Green LED flickers and at the destination point the LED remains on standby. After offloading the AGV makes a U-turn and follows the path back to the loading point through the reset point and wait for the next unit load.

The circle time of the AGV is evaluated as:

$$T_e = T_1 + \frac{L_d}{v} + T_u + \frac{L_e}{v}$$

Where

T_e = delivery cycle time (min/delivery)

T_1= time to load (min) is 0.05min

L_d = distance travel from load to unload station is 0.25m

v = carrier velocity is 0.31m/s; ($v = \frac{\pi DN}{60}$) where N = 90 rpm and D = 65mm

T_u = time to unloading station is 0.17min

L_e = distance the vehicle travel until the start of the next delivery station

Thus, $T_e = 0.05 + \frac{0.25}{0.31} + 0.17 + \frac{0.320}{0.31}$

$$T_e = 2.05\ min/delivery$$

Power requirement

The power requirement by the circuit component in table 1 is an average of 5 Volts. Thus, a voltage source with a minimum of 5 Volts output is required. However, the power consumption by Arduino + L293D motor driver + Green LED + IR sensor (3nos) is evaluated below:

$$I_T = (0.5 + 0.045 + 0.015 + 0.010) = 0.57 = 570\ m\ A$$

Then, power consumption by the AGV is given by: $P = IV$

$$P_{AGV} = 0.57 \times 5 = 2.85\ Watt$$

However, the current on the battery is 3600 mAh, so power rating of the battery at 5 Volts is:

$$P_{Batt} = 3.6 \times 5 = 18\ Wh$$

Hence, the battery will support the AGV operation for: $Time = \frac{18wh}{2.85w} = 6.3\ h \approx 5\ hours.$

Sensor positioning

The Infra-Red (IR) sensor position evaluation for accurate tracking of the dark path and effective path following at curved path is presented below according to (Zafri *et al* ., 2006);

$$w < |S_{RR} - S_{LL}| < \frac{w}{tan\theta_c} \qquad \textit{eqn. (1)}$$

Where

$|S_{RR} - S_{LL}|$ is the distance between the left most and right most IR sensor in millimeter (mm)

w is the width of the line being detected in mm and θ_c is the critical entry angle of the robot.

Thus;

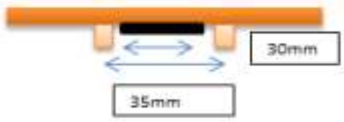

Fig. 10: Front view of the AGV

The width of the line has been determined by measurement to be 30mm. Setting the distance between the two front sensors to be 35mm, and rearranging the inequality in eqn. (1) to calculate the critical entry angle:

$$w < |S_{RR} - S_{LL}|\ tan\theta_c$$

$$\theta_c < tan^{-1}\frac{w}{|S_{RR} - S_{LL}|}$$

$$\theta_c < tan^{-1}\frac{30}{35}$$

$$\theta_c < tan^{-1}\ 0.85714$$

$$\theta_c < 40.6^o$$

Thus, $\theta_c = 40.6^o$. Hence, if the AGV attempts to enter a curvy path at an angle above this value, it will not be able to follow the line. Therefore, reduction in the distance between the two sensors would result to greater critical entry angle during transition to curvy paths and improved sensitivity to following the line thereby achieving better performance.

CONCLUSION AND FUTURE WORK

In this work presents the development of a prototype line following AGV for unit load application in an office environment with details of the hardware requirement. Although line following navigation technique is the cheapest in terms of installation cost. Nevertheless, appropriate sensor positioning to achieve effective tracking of curvy path is still a predominate challenge. This paper equally addresses this issue. Thus, presents the analysis for the evaluation of the critical entry angle of the AGV based on the sensor position. The AGV successfully traverse a unit load through the test path proving the effectiveness of the proposed method. Therefore, the AGV can replace the need of a clerical officer transferring mails between two point within an office environment. Whereas, the present work only considers material transport between two points, in the future we will like to consider material transport between several points within the office environment. This will require path flexibility which is not achievable with line following, thus, we will incorporate path planning and path tracking controller. Furthermore, loading and offloading deck will be provided at the destination points and the AGV carrier will be automated for automatic loading and offloading of the unit load at the corresponding deck.

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