Investigation And Improvement of Domestic Liquified Petroleum Gas (LPG) And Smoke Detection Robot with Wireless Control

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Abstract- This project work is on Liquefied Petroleum Gas (LPG) and Smoke Detection robot, using wireless control. It is important that LPG gas leaks are detected in time in homes and gas companies, due to the potential risk of fire and explosions. This work was characterized through the prime mover actuator (DC motor) of the robot, which was used to model the kinematics and dynamics of the robot, to design and simulate the Simulink model of the robot using Robotic Operation System (ROS) framework. Review of previous project work on similar topics, which clearly identifies the need for an autonomous robotic vehicle to navigate difficult or unsafe terrain. The work deployed computer aided software engineering (CASE) methodological approach in the design and simulation of the proposed four-wheel autonomous robot system.

Indexed Terms- Domestic liquefied petroleum gas, Smoke detection, and Wireless control

I. INTRODUCTION

The focus of this work is the investigation of the performance and improvement of domestic robot for Liquefied Petroleum Gas (LPG) and Smoke Detection using wireless control.

LPG is a hydrocarbon gas that forms an explosive medium when mixed with air. It is paramount to detect the leakage of this gas as early as possible. In a fire incident, the most critical period is the first five minutes, which is enough time for fire to build up enough heat energy to generate fumes and sustain itself. An early detection of an LPG leak is most important because it can easily prevent loss of lives and properties. On the other hand, smoke detection at the early stage of fire is very vital to prevent fire outbreak escalation and excessive damage due to fire. At the early stage of fire, the heat energy is still low and can be easily put out to prevent excessive damage. LPG and Smoke detectors are installed at various points especially in the kitchen and the surroundings of homes, hotels, industries etc. to warn occupants of any developing fire incident. In an enclosed area, LPG gas can act as an asphyxiant, hence dangerous to people even without a source of ignition. An LPG gas leak detection system will prevent such occurrence by alerting the occupants of a leak. An enclosure or atmosphere full of LPG is like a time bomb awaiting detonation at the slightest source of ignition. For a gas company, there is a risk of economic loss through LPG leakages. Potential areas of leak in a line such as flange should be monitored with a detector. There are places along and within the gas line where human beings cannot operate because of its hazardous nature or inaccessibility. A robot which can be remotely monitored can be used to detect any leakage at all times in order to curb any possibility of undetected leak which can lead to losses. If these hazardous areas are left unmonitored, product loss may continue unnoticed, resulting to huge financial loss.

Advancement in technology has brought about various applications to aid man in his day to day activity for saving time and cost. The advancement include the design and construction of robot that work according to its program. The advancement in robotics has increased its application in private organizations or firms, homes, schools etc. which ranges from the design and construction of robots carrying out the following; transportation task, communication, inspection and surveillance purposes in the case of security among others.

- Problem Statement

Flammable substances are quite difficult to quench when they are ignited. Fire for instance, when ignited, consumes everything on its path if not controlled. Fire fighters put their lives at great risks trying to extinguish fire in facilities such pipelines, factories, hotels, homes etc. Their health's are at great risk because of the release of toxic gases from the flames. These gases are health hazards to any living thing and can probably cause death. Some of these facilities are not equipped with detector systems for early detection. There are places along and within gas line and facilities where human beings cannot operate comfortably because of its hazardous nature or poor access. A robot which can be remotely monitored can be used to detect any leakage at all times in order to curb any potential fire incident which can lead to losses. If these hazardous areas are left unmonitored, workers lives are at risk and product loss may continue unnoticed, resulting to huge financial loss. Many researches have been conducted and many solutions proffered in terms of robots deployment. Some autonomous robots are already in existence but have some shortcomings such as inability to avoid obstacles in their path, slow response inaccuracy in speed and position of the robot, heavy weight of the robot, instability in communication network, sensitivity of the sensors, analogue nature of the sensors, inefficiency of the control mechanism etc. This work will deploy the pure pursuit algorithm in the investigation of the performance and improvement of domestic robot for Liquefied Petroleum Gas (LPG) and smoke detection using wireless Control.

Aim and Objectives of the Study

The aim of this work is focused on using a mobile robot for remote detection of LPG and smoke. The specific objectives include:

1. To characterize the prime mover actuator (DC motor) of the robot
2. To model the kinematics and dynamics of the robot
3. To design and simulate the Simulink model of the robot using Robotic Operation System (ROS) framework
4. To integrate and configure the computer system with the target hardware (robot), ultrasonic and MQ-2 sensors for full duplex remote communication
5. To carry out physical measurement using the developed 4-wheel robot

- Significance of the Study

There is no gain saying that when this work is completed that homes, offices, pipelines etc. will be adequately secured. Some of the advantages include but not only the following:

1. The work will go a long way in reducing losses in LPG firms
2. Fire outbreak could be nipped in the bud
3. Lives and properties are protected
4. It will enhance the benefits of automated fire fighting.

- Scope of the Study

The work will deploy Simulink software tool in modeling and simulation of the domestic 4-wheeled robot. Only the kinematics and dynamics of the robot were considered in the model. The ultrasonic sensor which can detect an object 20cm apart will be used for obstacle detection while the pure pursuit algorithm will be used for obstacle avoidance. MQ-2 sensor which can detect concentration of LPG and smoke within 200 – 1000 part per million (PPM), will be used in detecting the presence of LPG and smoke. The simulation will be carried out in Simulink environment using robotic operation system (ROS) with predetermined set paths.

II. MATERIALS AND METHODS

- Requirement specification

The proposed robot is a two-wheeled drive vehicle that is wirelessly controlled. It is required that the robot will have four wheels driven by two actuators (DC motors) incorporated in the front wheels. The two back wheels are to be propelled by the two front ones. The robot is expected to move autonomously, powered by a 12V 5A rechargeable battery. The operation of the robot will be based on detection of smoke and Liquefied Petroleum Gas (LPG) using MQ-2 Smoke LPG Butane Hydrogen Gas Sensor Detector Module as the sensing element. The detected signal will be transmitted wirelessly using Raspberry Pi 3 module.

- Software requirement

The software requirements include Matlab and Simulink, Proteus 8.0. There are other software requirements needed before real-time communication can be achieved. Such software includes; Microsoft Windows Software Development Kits (SDKs) 7 compiler and .NET Framework 4. The Windows 7 SDK provides the latest headers, libraries, metadata, and tools for building Windows 7 applications (Microsoft.com, 2017). The Windows 7 SDK, when used in conjunction with Visual Studio 2010, provides the optimum experience for implementation of various applications.

- Hardware requirement

The major hardware components needed include;
MQ-2 Smoke and LPG Detector Module: this is useful in gas leakage detection in home and industry. It is suitable for detecting H2, LPG, CH4, CO, Alcohol, Smoke or Propane. Due to its high sensitivity and fast response time, measurement can be taken as soon as possible. The sensitivity of the sensor can be adjusted by the potentiometer (Robu.in.com, 2019). The parameters of the module is as shown in table 3.1

DC motors: The parameters of the DC motor that were used are as shown in table 3.2.

Laptop Computer: The laptop computer is an Intel core i7 CPU running on Windows 8 operating system. A major requirement here is that the computer system should have a serial port connection

Wireless Tachometer: A digital wireless tachometer for measuring torque in both clockwise and anticlockwise direction

BASCOM-AVR: This is the Windows basic compiler used in downloading instruction codes to chips.

Raspberry Pi 3 module: The Raspberry Pi module for wirelessly transmitting signal between the computer system and target hardware i.e. the robot. The Raspberry Pi used has been defined in section 2.6

Power Supply: a 12V, 5A rechargeable DC battery

Table 1: Parameters of the MQ-2 Module

S/N	Parameters	Minimum	Maximum
1	Working Voltage Vcc	4.9V	5.1V
2	Heating Consumption PH	0.5Mw	800mW
3	Load Resistance R_L	Adjustable Ω	Adjustable Ω
4	Heater Resistance R_H		
5	Sensing Resistance R_S	30 Ω	30 Ω

(Source Robu.in.com, 2019)

III. METHODOLOGY

The Research work deployed computer aided software engineering (CASE) methodological approach in the design and simulation of the proposed four-wheel autonomous robot system. Since the DC motor is prime mover actuator of the robot, it is paramount that the motor is characterized to determine the actual values of the motor's parameter. The values determined through characterization were used in deriving the transfer function of the motor in Simulink. The modeling of kinematics and dynamics of the robot was carried out using appropriate mathematical functions. The parameters of the motor, kinematics and dynamics of the robot were used in the design and implementation of the proposed 4-wheeled mobile robot. The 4-wheeled robot was integrated with the MQ-2 and Ultrasonic sensors for data acquisition. Finally, the developed system was configured with the motor controller, Raspberry Pi module in order to achieve full duplex wireless communication.

Characterization of the DC Motor

The mathematical model of the DC motor has been developed by many researchers; one of the models is represented by Equation 3.1 as follows:

$$\frac{\theta_m(s)}{E(s)} = \frac{k_i}{s[(R+Ls)(Js+b)+k^2} \quad (1)$$

Where the symbol $\theta_m(s)$ represents the rotor angular displacement, $E(s)$is the input voltage, R is the resistance, Ls is the transform of the armature inductance, Js is the transform of the rotor inertia of the load and $k = k_i$, is the Torque constant. Substituting for angular velocity in equation (1) yields:

$$\frac{\omega_m(s)}{E(s)} = \frac{k_i}{(R+Ls)(Js+b)+k^2} \quad (2)$$

Where $\omega_m(s)$ is the transform of angular velocity. According to Okafor et al., (2017), before the motor can be used, it is important to understand how the motor behaves before subjecting it to simulation and physical tests for measurement or operation. The DC motor is represented electromechanically by equating electrical loses from the left hand side of figure 1 to the mechanical forces on the right hand side. Since the single transfer function describing the motor is already given in equation (1), it is important to determine the values of the variables (parameters) that were considered. The first parameter it's value was determined is the winding resistance of the motor (R_a). This was determined by using the short and open circuit test. The rotor was locked in a particular position and voltages were applied to the terminals of the motor incrementally. The current increases and reaches a steady value. The value is recorded and the rotor position is shifted to a new position and the same procedure was repeated. Many values were recorded then; Ohm's law was used to determine the value of resistance at each point of rotor change and the average of all the points were taken. The value of R_a achieved is shown in table 1.

The next parameter that was determined is the armature inductance (L_a). This was achieved using an Inductance Capacitance Resistance (LCR) meter. The value was determined by setting the meter to "series inductance" and connecting the terminals of the motor to the input of the LCR meter. The rotor position was changed to different positions and readings were taken. The average values of the recorded inductances were taken. The $L_a$value achieved is presented in Table 3.1. Another parameter value that was determined is the motor constant K. This was determined by multiplication of the no-load current with the armature resistance to determine the voltage drop (e_b) i.e. the back emf since the no-load current and speed were made available from the motor manufacturer through the datasheet. Thus, the motor constant was determined using the following speed-voltage equation:

$$\omega_m = \frac{e_a - e_b}{k_i} \quad (3)$$

where, ω_m is the rated speed of the motor in rad/sec. and e_a is the rated input voltage. The value of K and other parameters are shown in Table 3.1. The values of moment of inertia (J) and damping coefficient (b) which are the mechanical forces governing the operation of the DC motor are subject to the system material properties and load characteristics

Table 2 DC Motor Parameter Value

S/N	Parameters	Values
1	Moment of Inertia J	0.0064kg-m^2
2	Damping Coefficient b	0.001Nm/rad
3	Torque Constant Kt	0.010Nm A^{-1}
4	Electromotive force Constant Ke	3.40NmA^{-1}
5	Electrical Resistance	1.33Ω
6	Electrical Inductance	0.05H

- Modeling of Four-Wheel Robot

In robotics engineering, modeling is very vital in the design of a robot to perform a specific task. Robots can be modeled in two ways namely; Kinematics and dynamic models.

- Kinematic Model of a Four-Wheel Robot

According to Eneh el al. (2019), kinematics is the basic study of the behavior of mechanical systems. Robot kinematic modeling is done to achieve the mathematical expressions of the motion of the robot without considering the forces that affect it. The kinematics analysis of mechanical system determines the position, and velocity of the various mechanical elements forming the mechanism under consideration. The kinematics will help to determine where the robot will end up giving a certain steering angle and a number of wheel turns. The mobile robot is represented in a global coordinate frame in the x and y axis as shown in Figure 1

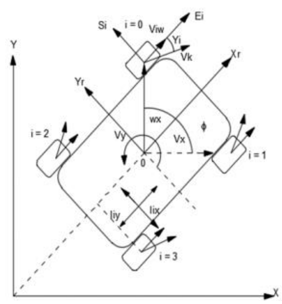

Fig 1: A 4 Wheel Robot in a Global Coordinate Frame (Jefri, 2006)

IV. EXPERIMENTAL TEST BED

One of the objectives of this work is to validate the developed and simulated 4-wheel robot to establish improvement. The essence of the experimental setup was for carrying out physical measurements using the developed model. In order to validate the work, Real-Time simulation was deployed on the target hardware. The reason for the deployment is to provide early proof that the developed model can operate in real life. Test was carried out in real time using the robot, and adjustments were made on the design until result proved satisfactory. Figure 2 shows the block diagram for the experiment.

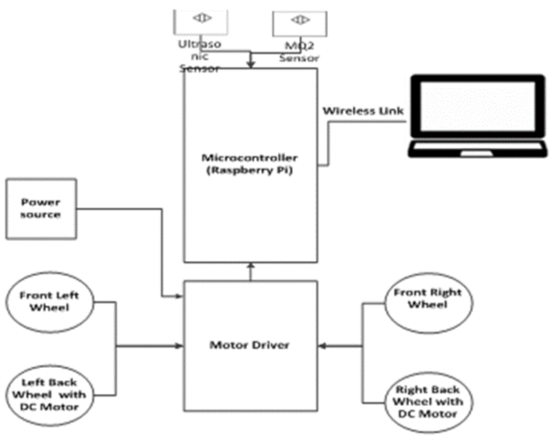

Fig 2: Experimental Setup for 4-Wheel Robot

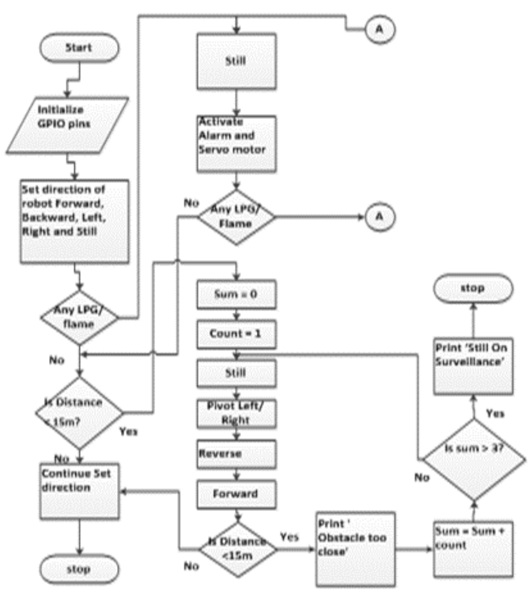

Fig 3: Flowchart of the Experimental Process

V. RESULTS AND DISCUSSIONS

- Initializing and Configuring the ROS platform

The develop robot system uses Robotic Operating System (ROS) to send and receive information from a MATLAB-based simulator. In the Matlab workspace, cd (tempdir) was typed to change the file directory to temporal directory so that the model file can be executed.

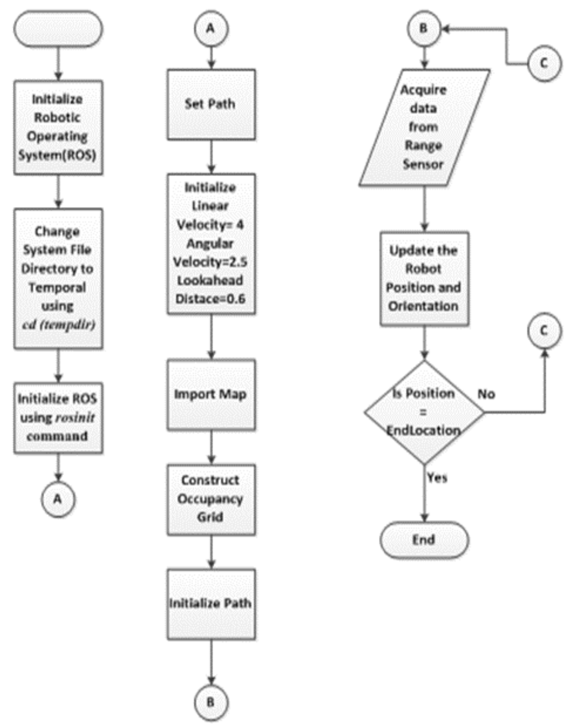

Fig 4. Flowchart for the ROS Simulation process

Then, the reference coordinate system was mapped out as shown in Figure 4.2. Here, the theta value is the angular orientation of the robot measured counterclockwise in radians from the x-axis. The current position of the robot is 0 radians.

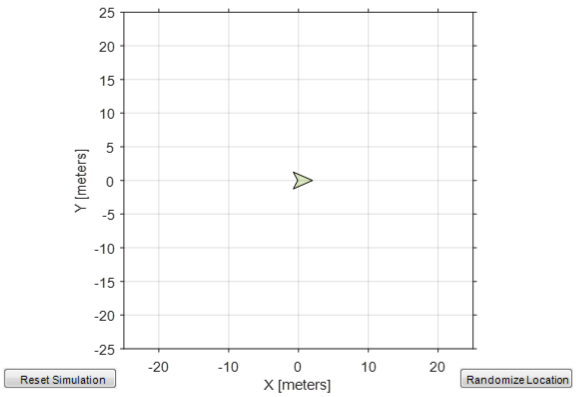

Fig 5. Mapping the Reference Coordinate System of the Robot.

- Path Planning

The essence of path planning is to compute an obstacle free path between two locations on a given map. This work deployed the Probabilistic Roadmap (PRM) path planner in the computation of obstacle free path. PRM path planner deploys randomly sampled nodes in the construction of a roadmap of a given map in the free space and interfacing them with each other (MathsWork, 2019). A path can be queried from a given starting point to a predetermined endpoint or goal on the map.

In this work, an occupancy grid map is used to represent the map using imported binary data. The concept is that, PRM uses this binary occupancy grid representation to deduce free space when sampling nodes in the free space of a map. Also, PRM does not consider the dimensions of the vehicle while computing an obstacle free path on a map. For a PRM path planner to locate an obstacle free path, then the start and end locations on the map must be defined. Path planner deployed in this work was created by MathsWork, (2019) and was into the Simulink using the following syntax; [filePath = fullfile(fileparts(which('PathPlanning')),'data','Maps.mat');
load(filePath)

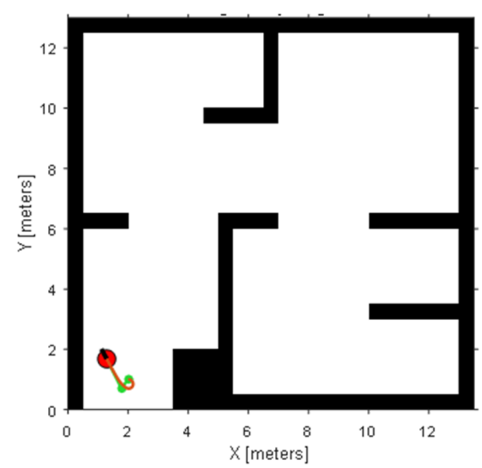

Fig 6. The Robot following Set Path 2.00   1.75.

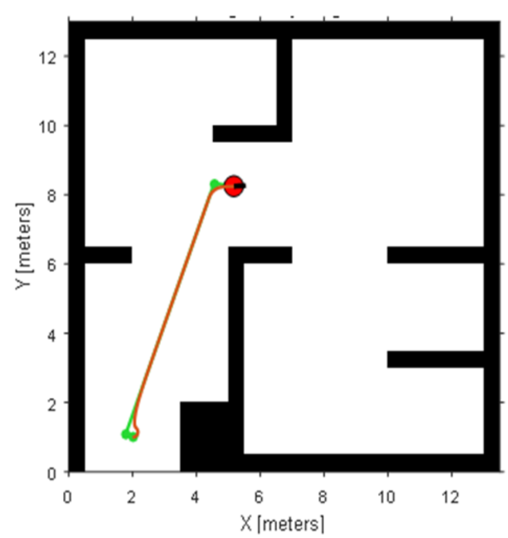

Fig 7 The Robot following Set Path 2.00   1.00; 1.25   1.75; 5.25   8.25.

- Configuration of the Robot, the Microcontroller and the Computer

The robot was fixed with the four wheels, the DC motor with the motor control, the Raspberry Pi, 12v battery, the ultrasonic and MQ-2 sensors, all interconnected and weighed to be 5.67kg. The Raspberry Pi uses Linux operating system with rasbian pre-installed in it. Rasbian is a Debian-based computer operating system for Raspberry Pi. The version of Rasbian used is Debian version 9 (Stretch). The Raspberry Pi also uses a Linux kernel version of 4.14. The Raspberry Pi has an HDMI output terminal for viewing both the command line interface and the graphical user interface. The command line terminal icon was used in writing the instruction codes.

A new directory was created using ‘cd robotics’ and to create a python script, the command ‘sudonano name.py’ is used; where ‘name’ is the name of the program’s name. The programs is typed, debugged and saved. To save a program, the command ‘ctrl x’ is used and ‘y’ (yes) is pressed to save with the same name. After the script was written and saved, next thing that was done is running of the program. For running the program, the command ‘sudo python name.py’ is used; where name is the name of the script used in saving the program. To stop the program running, the command ‘ctrl z’ is used.

The next thing done was to connect to a Wi-Fi network. The raspberry pi and Computer must be connected to the same network in order to establish a full-duplex communication that will enable data from the sensors to be transmitted and received. On the raspberry pi command line, the command ‘hostname –I’ is ran to know the IP address of the raspberry pi. The raspberry pi has a default username called ‘Pi’ and also to know the password. The password can be changed on the pi configuration pane. After retrieving the IP address of the raspberry pi, the next thing to do is to open the VNC viewer software. A space is provided to type in the IP address; then press enter. The system will prompt to provide the username and password. After enter input is selected, then, the raspberry pi interface can now be viewed from the computer.

The remote GPIO, the serial port and VNC can be enabled from the interface shown in Figure 8, according to requirement specification.

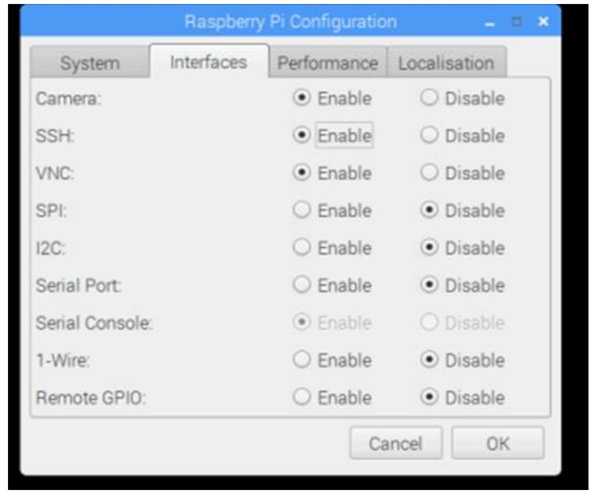

Fig 8: Raspberry Pi System Interface

The ultrasonic sensor was programmed to give accurate distance measurement. It was programmed to start avoiding obstacles placed at 20cm apart. The echo was connected to pin 16 and the trigger to pin 12. The ultrasonic sensor was made to check distance every 10millisecs for accuracy in obstacle avoidance. The MQ-2 sensor was connected to pin 18 of the raspberry pi. Once LPG or smoke is detected, the Raspberry Pi through the output pin no 27 transmit the information through the already established network to the Raspberry user interface in the computer.

The instruction code downloaded into the raspberry pi to control the individual wheels were presented in appendix C, the directions achieved were forward, backward, left and right with pivot (rotating at a point) as shown in the Figure 9

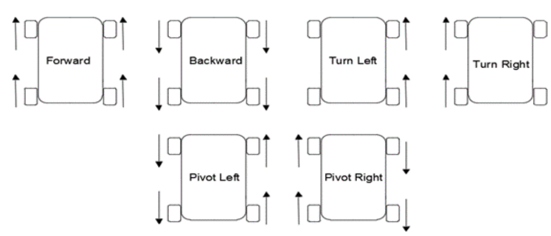

Fig 9: Directions achieved by the mobile robot

The left two wheels were connected together as also the right two wheels. The 5volts vdc and the Ground for the right wheels were connected to pins 7 and 11 respectively. While that of the left wheels were connected to pins 13 and 15 respectively. This was done to reduce the number of pins to be used since the wheels on the left turns toward the same direction when moving towards any direction and also same for the right wheels. The logic for achieving the movement of the wheels is as presented in Table 3, with False representing 0volts and True representing 5volts.

Table 3: the 4-wheel Robot truth table

Direction	Left Wheels	Right Wheels		
Pins	7	11	13	15
Forward	True	False	True	False
Reverse	False	True	False	True
Turn left	False	False	True	False
Turn Right	True	False	False	False
Pivot left	False	True	True	False
Pivot Right	True	False	False	True

The first physical measurement that was conducted is gas sensitivity test using LPG and smoke from burning papers. The gas and smoke concentration was giving in PPM as shown in Table 4.

Table 4: Result of Sensitivity Test

S/N	Gas in PPM	Smoke in PPM	Result
1	50	50	There was no communication between the robot and the computer system
2	100	100	There was no communication between the robot and the computer system
3	150	150	There was no communication between the robot and the computer system
4	200	200	Communication between the robot and the computer system was established
5	250	250	Communication between the robot and the computer system was established

From table 4, it can be seen that that the MQ-2 sensor incorporated in the robot can detect gas and smoke from 200ppm concentration. In the other experiment, wireless tachometer was used to measure the velocity of the robot. It was found that during experiment, the robot was moving with velocity of 5cm/s when compared with velocity of 4cm/s used in simulation, the robot made an improvement of 20%. This result was possible because of the lightweight materials used in construction of the frames. During simulation, the Look ahead Distance used is 0.6 while the distance of the grid that formed the obstacle is 20cm. From simulation result, it was observed that the range sensor was able to detect the obstacle placed 20cm apart at 15cm which 25% inaccuracy in detection but experienced an overshoot that led to oscillation. However, using the same Look ahead Distance of 0.6 during the physical measurement, the ultrasonic sensor was able to detect an obstacle placed 20cm apart at 16cm, which is 20% inaccuracy. When compare both result, it is evident that the robot achieved a 5% reduction the accuracy at which an obstacle is detected.

VI. CONCLUSION AND RECOMMENDATIONS

Conclusion

Investigation of the Performance and Improvement of Domestic Robot for Liquefied Petroleum Gas (LPG) and Smoke Detection Using Wireless Control was successfully developed using pure pursuit algorithm and Robotic Operating System in Simulink. The discrete form of the developed model for simulation in Simulink was achieved using appropriate transfer functions.

Recommendations

- Through critical evaluation of this work, some gaps were noted and apparently needed to be closed. In line with that, some areas of studies are recommended for further improvement.
- Since the power source needs to be recharged often, it is recommended that further studies be conducted in the area of sustainable power supply for the robot.
- Further studies should be conducted in the area of surveillance by incorporating camera.

Findings

- It was found that decrease in the look ahead distance introduces oscillation in the system
- That ultrasonic sensors can detect obstacle with 5% improvement compared to range sensors

- The linear velocity of the robot can be improved using light weighted materials in the construction the robot frames
- Pure pursuit algorithm with the robotic operating system provides a real time and high performance in terms of accuracy in robot control system
- Real time data transmission is achieved using Wi-Fi and Raspberry Pi

VII. ACKNOWLEDGMENT

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