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Autonomous Vehicle with Machine Vision and Integrated Sensor Suite Based on Internet-of-Things Technologies

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Abstract

This paper presents the development of an autonomous vehicle with integrated sensor suite with an obstacle detection and avoidance system which incorporates an electronic alarm system together with a 25-watt audio amplifier system. The proposed autonomous vehicle consists of seven sections, namely: *1)*. three HC-SRO4 ultrasonic sensors; *2)*. an L298N motor driver module; *3)*. a vehicle of dimension of 0.35 m (length) by 0.18 m (width) by 0.14 m (height); *4)*. an MQ-5 gas; *5)*. an MQ-2 smoke detector module; *6)*. an electronic alarm system which incorporates a 25-Watt audio amplifier; and *7)*. an Internet Protocol (IP) wireless camera system based on IPv4. Each of the three ultrasonic sensors has been attached to the front and both sides of the vehicle and they are able to detect obstacles within a 1m range. The H-bridge drive circuit built around L298N motor driver module in conjunction with the three ultrasonic sensors constitutes the obstacle detection and avoidance system and hence the autonomous nature of the vehicle. The MQ-5 and MQ-2 gas and smoke sensor module are attached to the top of the vehicle to detect hazardous gas and smoke in the atmosphere respectively. Two cascaded NE555N timer circuit forms the tone generator circuit. The output of the tone generator circuit is the input to the 25-watt audio amplifier built around TDA2050 integrated circuit. The outputs of the gas and smoke sensors are connected together via a four NAND-gate system to bias the tone generator circuit. The IPv4-based wireless camera system has been mounted on the autonomous vehicle for live streaming video of the environment at the base station. The performance of the autonomous vehicle with integrated sensor suite base on Internet-of-Things (IoT) technologies has been evaluated and its performance meets and satisfies the goal and aim of the study. The proposed autonomous vehicle can be adapted and deployed as a wireless security surveillance monitoring system and also in hazardous environments for waste management systems, mining sites, e.t.c.

Keywords

Autonomous Vehicle, Gas and Smoke Detection, Internet-of-Things (IoT), Machine Vision, Obstacle Detection and Avoidance, Wireless Communication

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1. Introduction

Maintenance work in radioactive and collapsed structure area is high risk for humans which makes it difficult for performing inspection jobs and testing in dangerous and hazardous areas under such condition. Therefore, an autonomous system has become essentially needed to perform such task to save life.

Today, mobile robot is often deployed in critical situations that are simply too dangerous for humans to handle as part of industrial operations, law enforcement or anti-terror measures, e.g. to identify a suspicious object or disarm a bomb. Owing to the extreme circumstances, these “manipulator vehicles” have to meet particular requirements.

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Exact maneuvering and precision handling of tools are two essential pre-requisites. Of course, the device also has to be kept as small as possible in order to allow access through narrow passageways and should also be capable of transmitting live visual coverage of the environment to the base station while also detecting hazardous gas on its pathway. Naturally, the drives used for such robots have to be equally impressive. Special high performance micro motors have become an essential component.

To date, there have been a number of successful attempts in designing obstacle avoiding robotic vehicles. These works differ by selection of sensors, path mapping process and the algorithms applied to set the operational parameters. There have been numerous projects in this arena using laser scanner, infrared sensor, GPS and multiple sensors to accomplish obstacle detection and avoidance [1–4].

Autonomous vehicles are generally designed to be controlled by a controller, computer or similar devices. Basically autonomous vehicles require an operator's vision and intelligence for guidance and navigation. The movement for autonomous vehicle itself has many methods such as wheels, legs and many more. This movement method is to ensure the smoothness of moving in different type of surfaces.

A simple wheeled vehicle may be easy in mechanical design, controlling, and the constructional parts, but it does not work efficiently on all kind of surfaces. On a rough terrain, it may perform poorly. The radius of a wheel could pass only a certain height of obstacle. To pass most of the obstacles that it encounters, larger wheel radius need to be designed. However, this approach is impractical in many cases.

This work proposes the design and implementation of an autonomous vehicle with integrated sensor suite which is programmed to maneuver automatically without human control. The followings are the merits and contributions of the proposed work to knowledge and the scientific community: *(i)* autonomous vehicle can replace human in high risk and dangerous job such as performing inspection job in collapsed strictures or radioactive areas; *(ii)* the autonomous vehicle can be adapted in the design of an autonomous orchard machine; and *(iii)* the proposed autonomous vehicle design and construction can be adapted for unmanned aerial vehicle designed for remote and area monitoring and space shuttle monitoring vehicle design.

The paper is organized as follows. The background knowledge with an overview of autonomous vehicles as well as state-of-the-art on the developments of autonomous vehicles are presented in Section 2. The design and development of the proposed autonomous vehicle with integrated sensor suite based on Internet-of-Things (IoT) technologies with machine vision is detailed in Section 3. A summary of the paper is given in Section 4 which discusses the two main focuses and contributions of the paper as well as the conclusion which also highlights the major contributions and directions on future developments as recommendations for improvements based on current limitations.

2. Background Knowledge

2.1. Overview of Autonomous Vehicles and Robot Cars

Several studies on autonomous vehicles have been conducted and reports. For instance an obstacle avoidance system for mobile robot using fuzzy logic and ultrasonic sensors [5–8] as well several other techniques have also been reported [3, 9, 10];

In another reported research, fuzzy logic-based and machine vision technology for an autonomous speed sprayer for orchards [11]; a Differential Global Positioning System-based (DGPS) automatic guidance system for automated steering control of a high-speed chemical application vehicle [12]; a design concept of an intelligent hospital service robot (IHSR) [13]; an RTK GPS for positioning, and fiber optic gyroscope (FOG) sensors to maintain vehicle inclination, for an automated six-row rice trans-planter [14]; an autonomous fire fighting mobile platform (AFFMP) to search for fire occurrence with flame sensors [15–19].

The developmental growth of mobile robot (ground vehicles) started with the Grey Walter and his tortoises [20]. One of the most documented autonomous vehicles is the Stanford Cart with obstacle avoidance [21]. Additionally, the Genghis Khan mobile robot had 12 motors, 12 force sensors and 6 pyro electric sensors obstacles avoidance sensors [22].

Modern research in autonomous vehicles and robot cars have also been reported [23–26] as well as the award-winning 2005 DARPA Grand Challenge robot nick-named "*Stanley*" equipped with laser range finder, GPS system, 6-DoF inertial measurement unit and wheel speed measurement unit for pose estimation with five Sick AG LiDAR units [27]. More reports on

2.2. Overview of the Proposed Autonomous Vehicle Design

The block diagram of the proposed autonomous vehicle is shown in Figure 1. A simple four wheeled drive (4-WD) configuration has been adopted for the design of the proposed autonomous vehicle which is equipped with gas and smoke sensors together with ultrasonic sensors. The 4-WD configuration was adopted because it allows for proper balancing of the vehicle and it also allows a greater torque to be achieved compared to a single wheel drive configuration.

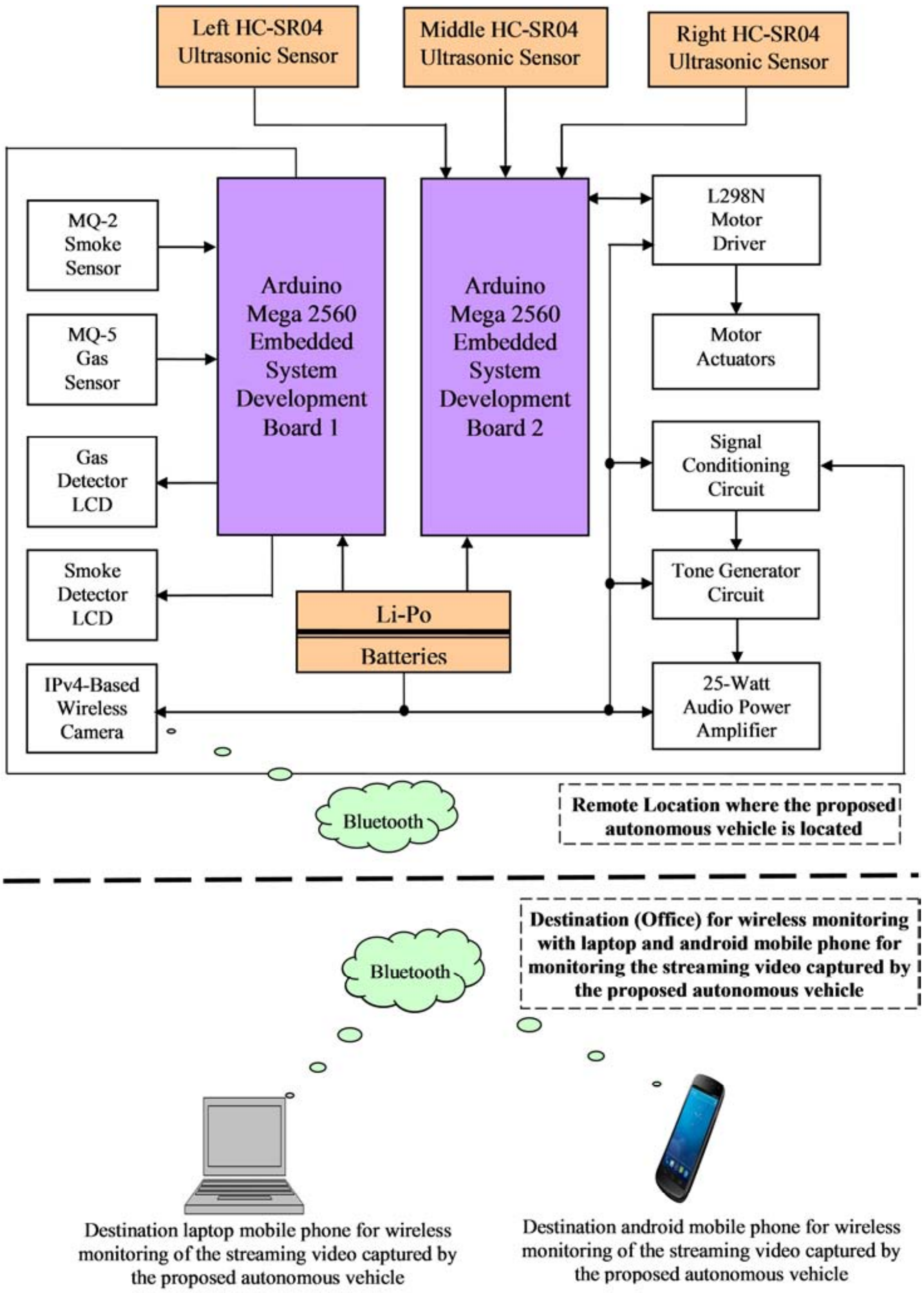

Figure 1. Block diagram of the proposed autonomous vehicle with integrated sensor suite.

The ultrasonic sensors on the vehicle are used in measuring the distance between the object and the vehicle. The ultrasonic sensors together with an L298N H-bridge board are used to maneuver the vehicle away from obstacles ahead of it to either right or left by changing the applied voltage across the load in opposite direction. An Arduino Mega 2560 development board is used as the heart of the autonomous vehicle which process different information collected from the sensors and gives a desired output. An MQ-2 and MQ-5 gas and smoke sensor are mounted at the top of the autonomous vehicle which are used to detect smoke and liquefied petroleum gas (LPG) respectively. The outputs of both the MQ-2 and MQ-5 sensors are connected via a four NAND gate system to a tone generator which triggers the alarm system built around a TDA2050 integrated circuit whenever either of smoke or LPG is detected. The smoke and gas sensor respectively together with two liquid crystal displays (LCD) were integrated on a single Arduino Mega 2560 microcontroller. An IPv4-based wireless camera is mounted on the autonomous vehicle to send live visual information of the environment to the base station for remote monitoring.

The main goal of this paper is on the development of an autonomous vehicle with integrated sensor suite based on Internet-of-Things (IoT) technologies. The main goal will be accomplished according to the following specific procedures which includes to: *(i)* design an autonomous vehicle with obstacle and avoidance system using H-bridge and ultrasonic sensors for its autonomous nature which incorporates a 25-watt audio amplifier; *(ii)* configure and interface an IP wireless camera system to a laptop for remote monitoring; and *(iii)* design a gas and smoke detecting system which incorporates a 25-Watt audio amplifier for alarm.

3. The Design and Development of the Proposed Autonomous Vehicle with Machine Vision

3.1. Description of the Block Diagram of the Proposed Autonomous Vehicle

The prototype of the vehicle should complement the autonomous behaviour of the vehicle. The autonomous vehicle is designed in such a way to navigate away from obstacle without human input and also able to detect hazardous gas. The vehicle is also designed in such a way to allow for the mounting of a wireless camera system. Therefore, to attain a fully autonomous behaviour, the proposed vehicle must have sensor arrangement for vision, steer mechanism for lateral control and drive mechanism for longitudinal control, communication modules for vehicle communication and control unit for controlling the autonomous nature of the vehicle. The proposed autonomous vehicle also allows for the attachment of gas and smoke sensors for detecting hazardous gas. Figure 1 show different modules used in the design of the proposed autonomous vehicle with integrated sensor suite which is based on IoT technology.

3.1.1. Vision System

For the autonomous vehicle to achieve the autonomous behaviour, it demands an efficient sensing method of its surroundings. An appropriate sensing arrangement is required to obtain information from its pathway as well as from its surroundings. The extent of the autonomous nature relies on the amount of information received from the environment which in turn depends on the sensor capabilities. Ultrasonic sensors have been used to see obstacles in the environment when the vehicle is in motion for proper navigation away from it. A Lenovo snowman wireless camera has also been adopted for the proposed vehicle which is to be used to transmit streaming videos of the environment to the base station wirelessly. With the use of this wireless camera, it is possible to know the type of substances causing obstruction.

Figure 2. Block diagram of the proposed autonomous vehicle with integrated sensor suite.

(a)

(b)

Figure 3. (a). SBEGO TT geared dc motor and (b). SBEGO rubber wheel.

3.1.2. General Dimensions of the Proposed Autonomous Vehicle

The dimensions of the proposed autonomous vehicle are as follows: *(i)* The length is 0.35 m; *(ii)* The breath is 0.18 m; and *(iii)* The height is 0.19 m. The shape of the autonomous vehicle is of great importance and can have an impact on the vehicle performance. The autonomous vehicle has a greater risk of finding its way through a narrow space. Figure 2 shows a computer-aided-design (CAD) diagram of the proposed autonomous vehicle.

3.2. Wheel Configuration and Wheels

The next step in the design process is the choice of a wheel configuration and the wheel for the development of the proposed autonomous vehicle. We decided to adopt the 4-WD configuration principle because it gives better balance of the vehicle on the ground compared to a three-wheel drive and also for the possibility of having greater torque. The size and material of wheel is an important parameter that autonomous vehicle can move its weight and payload efficiently. The wheel selection also affects the torque and energy requirement of the autonomous vehicle. For the proposed autonomous vehicle, four SBEGO rubber wheels and geared dc motor were used for the mobility of the autonomous vehicle [28]. The structure of the SBEGO TT geared dc motor is shown in Figure 3(a) while the SBEGO rubber wheel is shown in Figure 3(b). The details of the rubber wheel are shown in Table 1, while the specification of the geared dc motor is shown in Table 2.

Table 1. Specification of the SBEGO TT geared dc motor.

Parameters	Values
Operating voltage	3-7.5 V
Rated voltage	6 V
Max. no-load current (3 V)	140 mA
Max. no-load current (6 V)	170 mA
No-load speed (3 V)	90 rpm
No-load speed (6 V)	160 rpm
Max. output torque	0.098 Nm
Max. stall current	2.8 A
Output mode	2 sides
Gear ratio	1:120
Net weight	45 g

Table 2. Detail dimensions of the SBEGO wheel.

Parameters	Values
Outer diameter	65 mm
Wheel width	26 mm
Hub	6 mm

3.3. Steering Mechanism

An efficient steering mechanism to direct the vehicle in desired direction is needed. For the proposed autonomous vehicle, the steering is completely automated and the user has no control over the steer of the vehicle. As a result of this, a precise steer capability is required. In the proposed prototype vehicle, dc gear motor based steering mechanism is used for the vehicle steering. A differential drive steering scheme has been adopted to steer away from obstacles. The proposed autonomous vehicle uses three HC-SR04 ultrasonic sensors to detect obstacles [29–31]. Whenever the vehicle detects an obstacle within a 1m range, it causes the vehicle to steer away from the obstacle, therefore finding a path free from obstacles. The ultrasonic sensor has its own advantages and disadvantages which are discussed in later sections.

Table 3. Module pin definition for the HC-SR04 ultrasonic sensor.

Types	Pin Symbol	Pin Function Description
HC-SR04	Vcc	5 V power supply
	Trig	Trigger pin
	Echo	Receiver pin
	GND	Power ground

Table 4. Electrical parameters of the HC-SR04 ultrasonic sensor.

Electrical Parameters	HC-SR04 Ultrasonic Module
Operating Voltage	DC-5V
Operating Current	15 Ma
Operating Frequency	40 KHz
Farthest Range	4 m
Nearest Range	2 cm
Measuring Angle	15º
Input Trigger Signal	10 µs TTL Pulse
Output Echo Signal	Output TTL level signal proportional with range
Dimensions	45 x 20 x 15 mm

Figure 4. The HC-SR04 ultrasonic sensor [29–31].

3.4. Drive Mechanism

Autonomous vehicle inherently demands mobility. Therefore, an appropriate driving mechanism is required. In the proposed autonomous vehicle, dc motors are used for longitudinal drive mechanism due to low power consumption and its availability. *Four Makeblock TT* geared dc motors and rubber wheels have been used for the mobility of the vehicle [28].

3.5. Control Unit

The control unit handles all the information received from the sensors. It is the termination hub for data from all the sensors and the origin for the control signals of the actuators. The microcontroller should satisfy all the requirements for the autonomous vehicle control. An Arduino Mega 2560 microcontroller have been used as the control unit for the proposed autonomous vehicle [29–33].

3.6. The HC-SR04 Ultrasonic Sensor

The HC-SR04 ultrasonic sensor [29–31] is a device that is capable of measuring the distance to an object by using sound waves. It measures by sending a sound wave at a specific frequency and listening for that sound wave to bounce back. By recording the elapsed time between the sound wave being generated and sound wave bouncing back, it is possible to calculate the distance between the sonar sensor and the object. The HC-SR04 ultrasonic sensor used for obstacle detection is shown in Figure 4. The module pin description of the HC-SR04 ultrasonic sensor is shown in Table 3 while the electrical parameters are shown in Table 4.

3.7. Actuating Mechanism

The dc motor based longitudinal speed actuation is being adopted for the prototype autonomous vehicle.

3.7.1. DC Motors, Drive Mechanism and Speed Measurement System

The proposed autonomous vehicle uses dc motors in driving module to propel the vehicle. The dc motors provide the momentum required to move the vehicle. All drive power necessary is supplied over the two wires of each motor. The proposed autonomous vehicle uses four *Makeblock TT* geared dc motors which forms a differential drive mechanism. The dc motors are driven by an H-Bridge motor driver built around an L298N integrated circuit. The dc motor speed is varied according to the voltage difference applied between its two terminals. The polarity of the applied voltage will change the direction of rotation. The signal from the Arduino mega 2560 microcontroller controls the H-bridge which in turn drives the motor. The implementation of a single dc motor on the L298N H-bridge motor driver into the Arduino Mega 2560 microcontroller is shown in Figure 5.

PWM signal from the microcontroller is connected to IN1 and IN2 terminals of the L298N motor driver as shown Figure 5. The pins D12 and D13 are the two PWM pins as labeled on the Arduino Mega 2560 microcontroller [32]. The *Makeblock* TT geared dc motor is connected to OUT1 and OUT2 terminals of the L298N motor driver [34]. The signal 'PWMR' is the PWM signal to the right motor from pin 13 and 12 of the Arduino Mega 2560 microcontroller which are connected to pin 7 (IN2) and pin 5 (IN1) of the motor driver respectively as shown in Figure 5. The output of the H-Bridge is taken from OUTR1 (pins 2, 3) and OUTR2 (pins 13, 14) to the two terminals of the DC motor [35]. The structure of the dc motor shown in Figure 3(a) has been adopted for the propulsion of the autonomous vehicle.

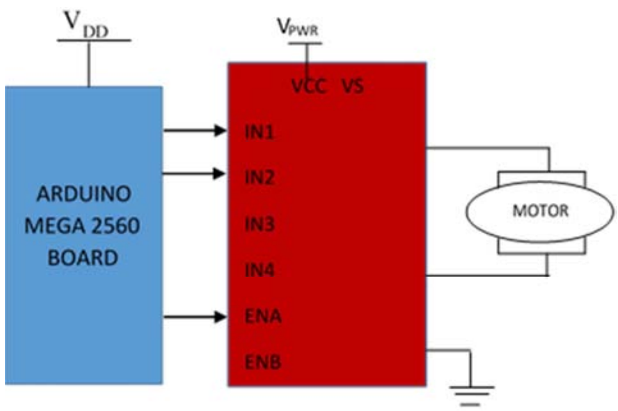

Figure 5. A DC Motor with L298N Motor Driver.

3.7.2. The L298N Motor Driver

The L298N driver is an H-bridge development board which is used for the control of motors [34]. This motor driver shown in Figure 7 is used to control the four *Makeblock TT* geared dc motors. The L298N motor driver enables the rotation of the motor in both clockwise and anti-clockwise direction as a result of the change in polarity which is dependent on HC-SR04 ultrasonic sensors. The L298N Motor Driver is used to drive the dc motors that work with up to 12 V dc. The L298N motor driver has two channels and each channel supports a 2 Ampere connection. This motor driver also can be used to drive stepper motors as well. The L298N motor driver module pins description is shown in Table 5 while the electrical parameters are shown in Table 6.

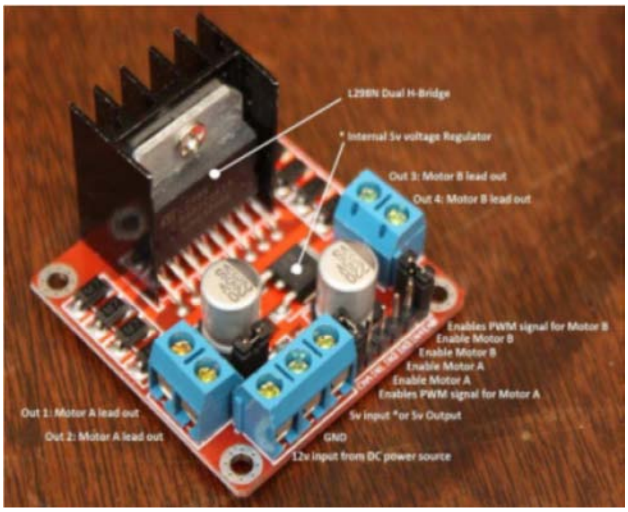

Figure 6. The L298N motor driver module [34].

Table 5. Module pin description of the L298N motor driver.

Pin Symbols	Pin Function Description
GND	Power ground
VCC	Power supply
ENA	Enables PWM signal for motor1
IN 1	Enable Motor 1
IN 2	Enable Motor 1
IN 3	Enable Motor 2
IN 4	Enable Motor 2
ENB	Enables PWM signal for Motor 2

Table 6. Specification of the L298N motor driver.

Electrical Parameters	L298N Motor Driver Modeule
Logical Voltage	5 V
Drive Voltage	5 V – 35 V
Logical Current	0-36 mA
Drive Current	2 A
Max Power	25 W

3.8. Configuration and Interfacing of the Lenovo Snowman IPv4-Based Wireless Camera for Remote Monitoring

As wireless camera has become more compact and affordable, they have become a practical alternative to the traditional webcam or security camera. One advantage to wired solutions is that they are easy to connect, and computers typically support them in plug-and-play fashion. Wireless solutions, on the other hand, require communication via a wireless network, and that configuration process isn't always as user friendly as connecting a universal serial bus (USB) cable. For the purpose of this work, we have adopted the use of the Lenovo Snowman IPv4-based wireless camera [36] as shown in Figure 7. The specifications of the Lenovo snowman IP wireless camera are shown in Table 7. The IPv4-based wireless camera has a maximum transmitting range of 15 m.

Figure 7. The Lenovo Snowman IPv4-based wireless camera.

Table 7. Specification of the Lenovo Snowman IPv4-Based Wireless Camera.

Parameters	Lenovo Snowman IPv4-Based Wireless Camera
Dimension	78 x 78 x 125.5 mm
Power supply	DC 5-V
Supported mobile system	iOS, Android
Video comprehension format	H.264
Viewing angle	120°
Lens	3.6 mm
Connectivity	IP/Network wireless
High definition (HD)	1080P (Full-HD)

3.8.1. Configuration and Interfacing of the Lenovo Snowman IPv4-Based Wireless Camera to a Laptop

In order to get the IP wireless camera working on an Acer Aspire PEW71 laptop system, the software (device client) was installed in the laptop which serves as an interface between the IP wireless camera and the Laptop for communication. After successful installation was recorded, the IPv4-based wireless camera was powered ON through a USB cord that was connected to a battery which output voltage was 5 Volts. On the laptop, the Wireless Fidelity (Wi-Fi) network was switched ON to allow the laptop search for the IPv4-based wireless camera network. After successful search of the IPv4-based wireless camera network, the laptop and the IPv4-based wireless camera were connected via Wi-Fi for data exchange. On the laptop, the "device client" software was launched and the view of the environment was seen. The image capture by the IPv4-based wireless camera as viewed from the Aspire PEW71 laptop system is shown in Figure 8.

3.8.2. Configuration and Interfacing of the Lenovo Snowman IPv4-Based wireless Camera to an Android Phone

In order to get the Lenovo Snowman IP wireless camera working on an android phone, an application known as NETCAM was downloaded from the android play store and was successfully installed for proper interfacing of the IP wireless camera to the android phone. A Tecno DroidPad 7C Pro android phone was selected for this purpose due to its large screen size. The IP wireless camera was switched ON and the mobile hotspot of the android phone was set ON to search for the IP wireless camera network. After search was successful, the IP wireless camera network was connected to the android phone network for the exchange of data. The NETCAM application was lunched to begin the process of viewing the image captured by the camera. On the NETCAM app, the IP wireless camera device was added which then enabled us to remotely monitor the environment from the android phone. The screenshot shown in Figure 10 shows the image viewed from the Tecno DroidPad 7C Pro android phone captured by the IPv4-based wireless camera.

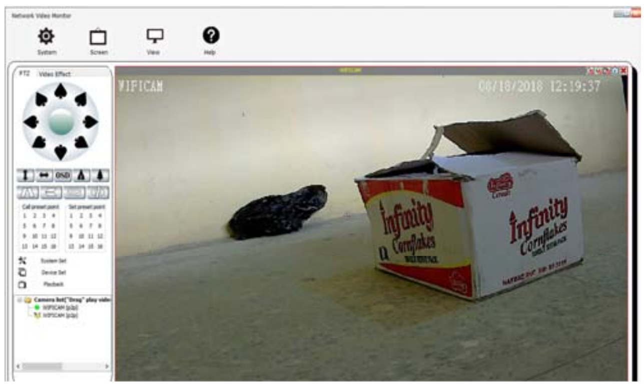

Figure 8. Image viewed from the laptop captured by the IP wireless camera.

Figure 9. Image viewed from the android phone captured by the IP wireless camera.

3.9. Development of the Proposed Autonomous Vehicle

In this section, the development, implementation and deployment of the autonomous vehicle is presented. The components which make up the proposed autonomous vehicle are shown in Figure 1. The stages of the development of the autonomous vehicle are in three phases namely: *(1).* The design of the vehicle platform which gives the vehicle its autonomous behaviour; *(2).* the design of the gas and smoke detecting system which enables the autonomous vehicle to detect hazardous gas; and *(3).* The configuration and interfacing of an IP wireless camera system for remote monitoring which has been discussed in previous section.

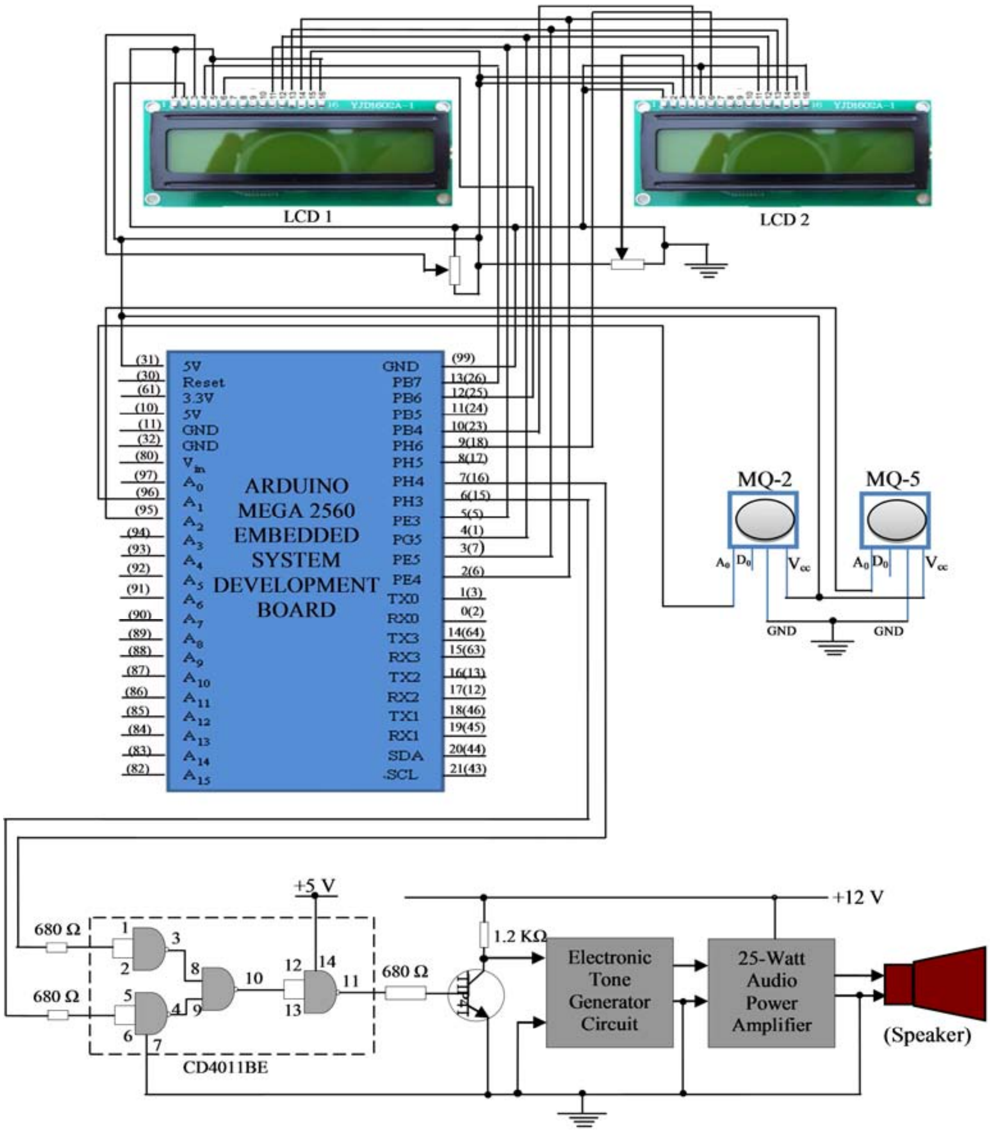

Figure 10. The block diagram implementation of the gas and smoke detection system incorporating an electronic alarm integrating a 25-Watt audio power amplifier based on IoT technology with a signal conditioning circuit built around CD4011BE.

The parts required to design the first stage of the autonomous vehicle consists of an Arduino Mega 2560 microcontroller, three ultrasonic sensors, an L298N motor driver and the drive motors which are all shown in Figure 1. The HC-SR04 ultrasonic sensors are used to detect obstacles. The HC-SR04 ultrasonic sensor in conjunction with the L298N motor driver allows the vehicle to navigate away from obstacles without human input, thereby giving the vehicle its autonomous nature. The stage two of the development of the autonomous vehicle requires that the vehicle will be able to detect hazardous gas along its path if present. The MQ-2 sensor, MQ-5 sensor, signal conditioning circuit, tone generator, 25-Watt audio power amplifier and an Arduino microcontroller as shown in the block diagram of Figure 1 were used to design the gas and smoke detection (GASMOD) system of the autonomous vehicle as shown in Figure 10. The complete description of the GASMOD system of Figure 10 adapted in this work can be found in [33]. The stage three of the development of the autonomous vehicle requires that autonomous vehicle is able to send live video of the environment to the base station for remote monitoring. An IPv4-based wireless camera which is a part of the block in Figure 1 has been configured and interfaced with an Acer Aspire PEW71 laptop system and a Tecno Droipad 7C Pro android phone for remote monitoring of the environment. However, stage three in the design of the proposed autonomous vehicle design has been discussed in the previous sub-sections 3.8 which deals with the configuration and interfacing of the Lenovo Snowman IPv4-based wireless camera for remote monitoring.

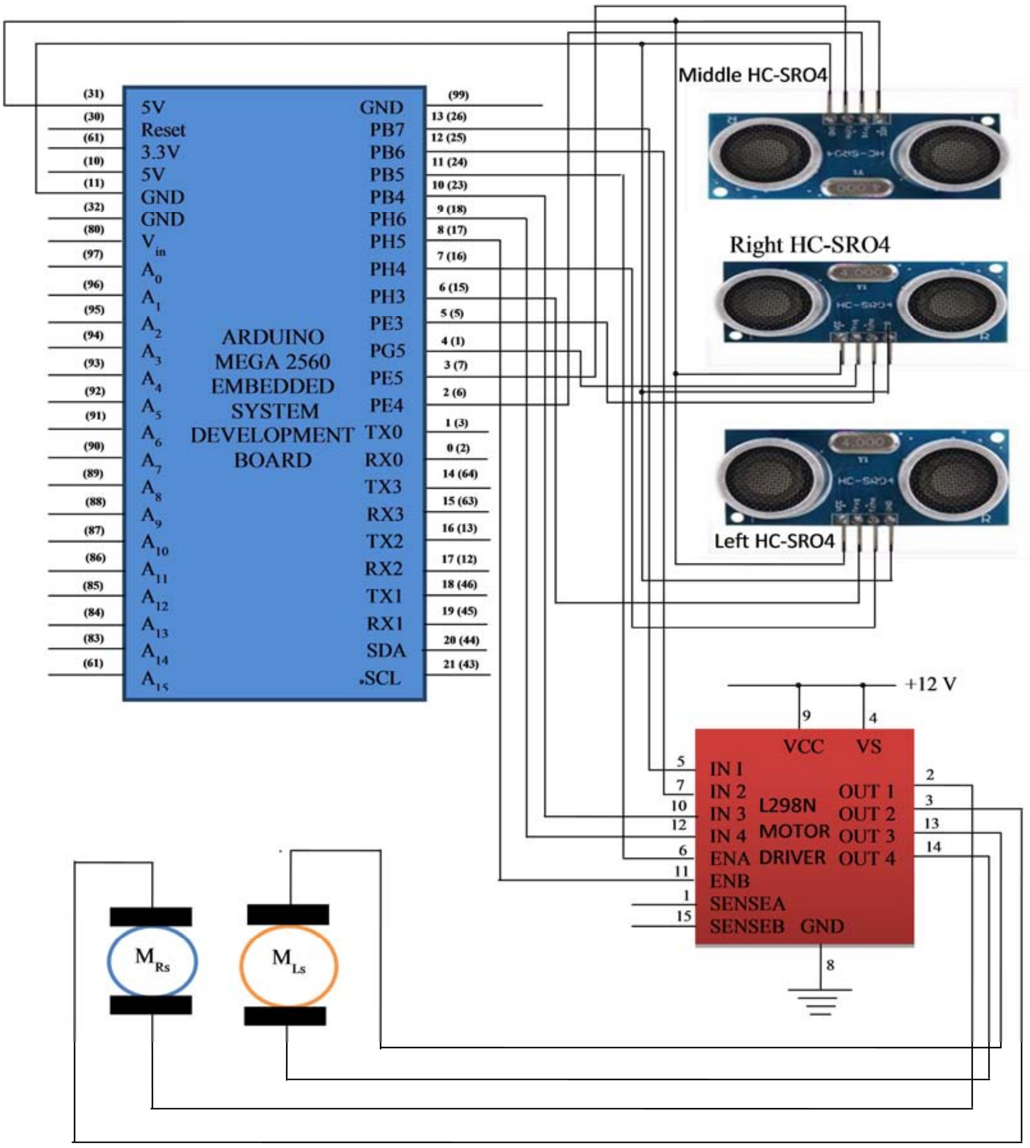

Figure 11. Complete Interface of the L298N motor driver, dc motors and the ultrasonic sensors into the Arduino microcontroller.

3.9.1. Design of the Autonomous Vehicle

As discussed in previous sections, the first stage of the design of the autonomous vehicle is the design of the vehicle platform. The vehicle platform as a dimension of 35 cm length, 19 cm width and a height of 18 cm. Four *Makeblock TT* geared motors and four rubber wheels are used for locomotion of the vehicle. The three ultrasonic sensors are attached to the left, right and middle of the vehicle. The Arduino Mega 2560 microcontroller is the heart of the autonomous vehicle and it process all the information received from the ultrasonic sensors. The L298N motor driver is used as an interface between the *Makeblock TT* geared motor and the Arduino microcontroller to allow the motors rotate in clockwise and anti-clockwise direction respectively as at when needed. The complete interface diagram of the components used in the first stage of the development of the autonomous are shown in Figure 11. The algorithmic flowchart which is programmed in C++ to give the autonomous vehicle its behaviour is shown in Figure 12 while the working principle of the proposed autonomous vehicle is discussed in next sub-section.

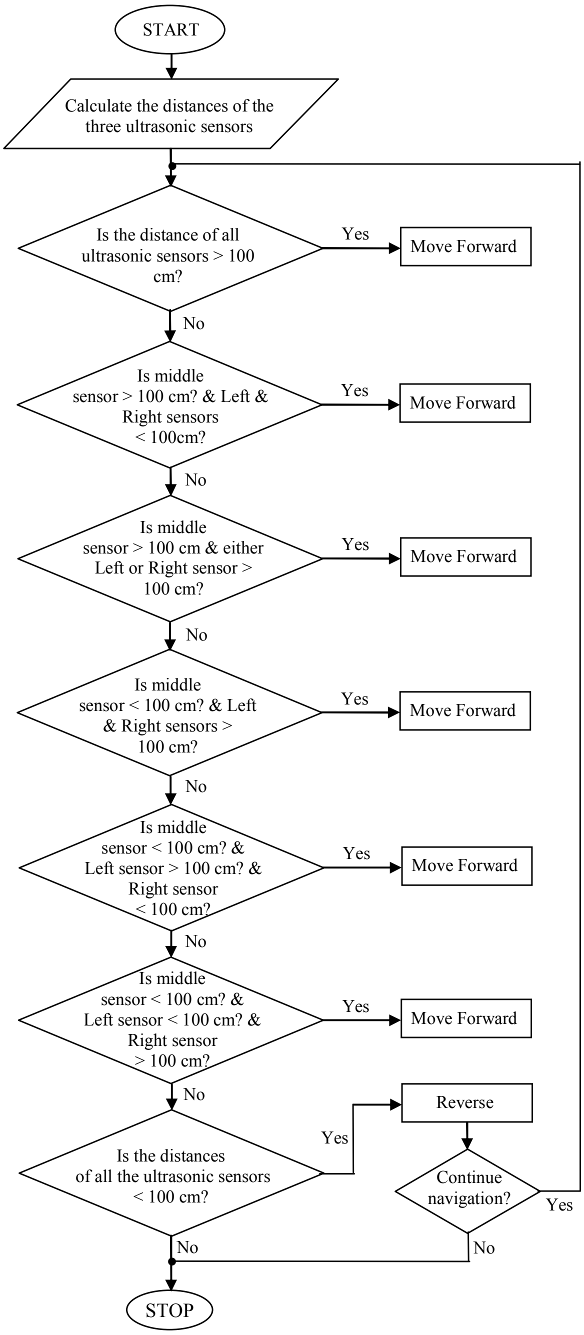

Figure 12. Flowchart of the Autonomous Vehicle operation.

3.9.2. Working Principle of the Autonomous Vehicle

The autonomous vehicle with integrated sensor suite developed is capable of detecting and avoiding obstacles with the help of three ultrasonic sensors to measure the distance to surrounding objects and a L298N motor driver which helps the motors to change direction by changing their polarity. The rules/program the autonomous vehicle will follow is written in C++ and it is embedded into the Arduino Mega 2560 microcontroller. The description of the program is shown in the flowchart in Figure 12. The general program for the autonomous operation is created for robot rules. At first step, the program read all sensors value that is attached to the robot. Then the distance value of the ultrasonic sensors is calculated. The program receives ranging data from the sensors then uses this to conduct its operations.

When the autonomous vehicle is powered, the three ultrasonic sensors take readings of its surroundings simultaneously. The middle ultrasonic sensor takes major priority over the left and right sides ultrasonic sensors. The proposed autonomous vehicle keeps moving in forward direction as long as the reading of the middle ultrasonic sensor is greater than 100 cm irrespective of the readings recorded in the left and right sides ultrasonic sensors as described in the flowchart. If the middle ultrasonic sensor reading is below 100 cm, the autonomous vehicle stops. The distances of the left and right ultrasonic sensors readings are compared to determine what direction to navigate to. If the measured distances of the right and left ultrasonic sensor are greater than 100 cm, the autonomous vehicle will navigate to the left direction. If the reading of the left ultrasonic sensor is greater than 100 cm and right ultrasonic sensor is less than 100 cm, the autonomous vehicle will navigate to the left direction. If the reading of the right ultrasonic sensor is greater than 100 cm and the left ultrasonic sensor reading is less than 100 cm, the autonomous vehicle will navigate to the right. If at any point in time the three ultrasonic sensors readings are less than 100 cm at the same time, the autonomous vehicle stops, it reverses backward and turns left if the left ultrasonic sensor is greater than 50 cm. The autonomous vehicle also triggers an alarm whenever either of smoke or LPG is detected while it continuously sends live streaming visual information to the base station as long as the transmitting range is not exceeded.

3.10. Development of the Gas and Smoke Detecting System

Air pollution can be defined as the presence of toxic chemicals or compounds (including those of biological origin) in the air, at levels that pose a health risk. In an even broader sense, air pollution means the presence of chemicals or compounds in the air which are usually not present and which lower the quality of the air or cause detrimental changes to the quality of life (such as the damaging of the ozone layer or causing global warming). As discussed in the overview of the study in Section 2.2, the proposed autonomous vehicle is expected to detect the presence of smoke and LPG and give an alarm sound whenever the level of this hazardous gas exceeds its preset threshold value [33]. As a result of this, a gas and smoke detecting system is designed which incorporates a 25-Watt audio electronic power amplifier for alarm which is part of the embedded system of the autonomous vehicle as described in the block diagram of Figure 1. The gas and smoke detecting system is made up of two LCDs, MQ-2 smoke sensor, MQ-5 gas sensor, a signal conditioning circuit which is made up of four NAND gate system and a transistor, a tone generator and a 25-Watt audio amplifier which is built around a TDA2050 integrated circuit as shown in the block diagram of Figure 10 [30, 31, 33].

3.11. Li-Po Battery System

Two Li-Po batteries connected in series generates the required power for actuators and other components for the entire proposed autonomous vehicle. It is preferred due to its light weight and small thickness. Two 4.2 V, 4.2 A-hr Li-Po battery cells are connected in series in order to provide 8.4 V to feed the microcontroller and the motor driver. Four 3.7 V, 2.6 A-hr battery has been used for supplying power to the gas and smoke detecting system. Two batteries each are connected in series to provide 7.2 V each and both are connected in parallel to produce amperage of 5.2 A-hr while a power bank with output voltage of 5 V is used to power the Lenovo snowman IPv4-based wireless camera.

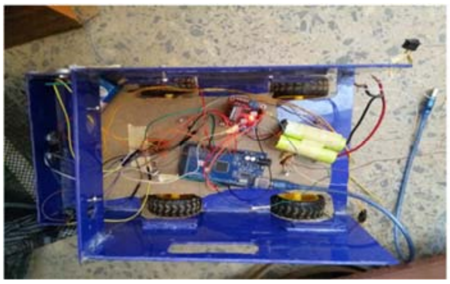

Figure 13. Development phase and components integration of the proposed autonomous vehicle.

4. Summary

In summary, Figure 13 development phase as well as the integration and coupling of various components of the proposed autonomous vehicle interfaced with the Arduino microcontroller and the Lenovo Snowman IPv4-based wireless camera. However, Figure 14 shows the fully designed, constructed and tested proposed autonomous vehicle with the respective integrated sensor suite based on the IoT technologies.

Figure 14. The fully designed, constructed and tested proposed autonomous vehicle with integrated sensor suite based on the IoT technologies for obstacle detection and avoidance, gas and smoke detection as well as wireless streaming video transmission of the real-time camera coverage to remote base location.

4.1. Discussion

The two main goals of this work were to design: *1).* an autonomous vehicle with integrated sensor suite based on Internet-of-Things (IoT) technologies. The autonomous vehicle used ultrasonic sensors for detecting obstacles due to their availability and cheap cost; and *2).* a gas and smoke detecting system which is embedded into the autonomous vehicle likewise an IP wireless camera system to send live visual information of the surroundings to the base station.

The result of this research shows that the autonomous vehicle was able to navigate away from obstacle without human input and was also able to detect the presence of LPG and smoke in its environment while in motion. The developed autonomous vehicle was also able to send visual information of its surrounding via an IP wireless camera to the base station via Wi-Fi. The tasks accomplished in this current proposed work are as follows:

(i) Successful development of the autonomous vehicle with a few mechanical components to add two more functions to the main body, namely the gas and smoke detecting system holder and the camera holder;

(ii) Optimization of the Arduino microcontroller development board which was used to control the motors smoothly;

(iii) Carefully choice of a IP wireless camera with great value at a relatively low cost which was mounted on the autonomous vehicle to send visual information to the base station via wireless technology;

(iv) Successful development of the software to detect the obstacles and send out signals to control the motors; and

(v) Successful development of the software to detect LPG and smoke simultaneously and send out signals to trigger the 25-watt audio amplifier for alarm.

4.2. Conclusion

An autonomous vehicle with integrated sensor suite based on IoT technologies of dimension “0.35m x 0.19m x 0.18m” was developed. The autonomous vehicle was embedded with ultrasonic sensors, smoke and gas sensors and an IP wireless camera system. At the end of the development, the autonomous vehicle meets the specified objectives of the design. The following deductions were made from the study:

(i) The ultrasonic sensors were able to measure the distance of the vehicle to the object causing obstruction.

(ii) The autonomous vehicle was able to navigate away from obstacle with the help of the HC-SR04 ultrasonic sensors in conjunction with the L298N motor driver;

(iii) The autonomous vehicle was capable of detecting the

presence of LPG and smoke and also giving an alarm sound;

(*iv)* The autonomous vehicle was able to send live visual information to the base station;

(v) The programs embedded into the Arduino microcontrollers were properly executed by the autonomous vehicle; and

(vi) The autonomous vehicle could be used in place of humans in getting information from the environment of a collapsed factory involved in the production of gas that could be harmful to humans if exposed into the atmosphere.

4.3 Future Directions

Based on this study of autonomous vehicle with integrated sensor suite based on IoT technologies, it was observed that the developed autonomous vehicle sometimes fails to navigate away from obstacles due to the effect of crosstalk which arises as a result of multiple use of ultrasonic sensors for distance measurement. The autonomous vehicle was only able to detect the presence of smoke and LPG. The transmission range of the IP wireless camera system to the base station is just below 12m range which made it difficult to extend the base station. Based on the limitations of the developed autonomous vehicle, the following recommendations can be made, namely:

(i) The use of different types of distance sensors such as Lidar, radar sensor, camera etc. should be used with ultrasonic sensors;

(ii) More gas detectors that detects beyond smoke and LPG should be embedded into the autonomous vehicle;

(iii) The IP wireless camera should be configured in a way that the live streaming visual information could be viewed through the Internet;

(iv) The autonomous vehicle could be modified to move over obstacles if possible based on the object seen by the camera causing obstruction; and

(v) GPS should be embedded into the autonomous vehicle for mapping out locations.

Conflict of Interest

The authors declare that they have no conflict of interest.

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