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Prototyping an IoT-enabled Autonomous Unmanned Ground Vehicle Using SLAM

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Abstract— Any system that has a capability to perform any dull, difficult, dangerous, or dirty task without any support of human being, such type of system is known as Autonomous systems. In today's era, there is a boom of such autonomous systems and in fact they are now gradually replacing human beings. In the catalogue of such autonomous systems robotic manipulators are very common and famous. This is because of their ability to pick and drop the heavy and sensitive packages from one place to another. There are also various autonomous vehicles that detect the safe and familiar paths, this detection is known as path following and tracking phenomena. These autonomous vehicles have more accuracy than an ordinary human being and with their usage one may maximize the efficiency and productivity of any industrial plant. Similarly in the field of information and communication technology, Internet of things (IoT) has been also one the trending topics. Thus, this manuscript presents the prototyping of an IoT-enabled autonomous unmanned ground vehicle (AUGV) which will not only follow the familiar path autonomously and avoid the obstacles using simultaneously localization and mapping (SLAM) but will also update the fundamental parameters of its surroundings i.e., temperature, pressure, humidity, detection of hazardous gas and exact location on provided internet protocol (IP). The reader will be able to understand the implementation of SLAM based path following and IoT-based data acquisition. These features make this prototype one of its kinds to be opted in various conditions.

***K**eywords—Autonomous, UGV, Robotics, SLAM, IoT-enabled systems, Data Acquisiton.*

1 Introduction

There are several situations which are termed as 4D situations such that dull, difficult, dangerous, and dirty where humans cannot survive. Thus, for such conditions, these IoT-enabled autonomous unmanned ground vehicles are most recommended options. Considering a location for which our military agencies need the surveillance and acquire the visuals [1] including the runtime temperature, pressure, humidity, detection of hazardous gases [2] and exact longitude and latitude data points. To send someone in such area (enemy's territory) is bit risky. Thus, this is one of the genuine problems and keeping this issue in mind; paper proposes the prototyping of an IoT-enabled autonomous unmanned ground vehicle using simultaneous localization and mapping (SLAM) that not only plan the path with visual recording but will also acquire the runtime data i.e., temperature, pressure, and exact location. To prototype the unmanned ground vehicle, one must be aware of the fundamentals of robotics and some high-quality sensors. Unmanned ground vehicle is one of the autonomous systems that operates on earth surface and plan the path by itself and identifies the possible obstacles in between its path. Apart from unmanned ground vehicle, one may find unmanned aerial vehicle and unmanned underwater vehicle too, as shown in figure 1.

Fig. 1. Types of autonomous unmanned vehicles

The other terminology is "Dynamics" that deals in the mathematics to produce some of the physical quantities such that desired force and torque [1]. Thus, it is to share that the proposed IoT-enabled UGV is operated dynamically via 24 DC Volt battery source which can be recharged.

There are various ways to monitor the location and do surveillance but among the most suitable way to acquire the data is through internet of things [2]. One may use this feature and use some of the sensors to acquire different type of data. The deployment of such feature is also easy because it has been implemented before in many wearable products [2]. Unmanned ground vehicle (UGV) covers the distance based on one physical frame of reference which is unique as per the basics of a coordinate system. The proposed UGV follows the path based on SLAM technique that is dependent over the two-points distance formula. For avoiding the collisions, the UGV is equipped with LiDAR v3 sensor. This equip the UGV with an ability to explore the map determine whether the territory is known to him or not. The GPS sensor provides the UGV's location. There are several strategies i.e., dead-reckoning method that determines the exact position of UGV by implementing encoders beneath wheels.

The dead-reckoning method involves the counting of wheel rotations but if there is an occurrence of slippage then the specific UGV will stop following the path and one may not be able to troubleshoot the issue. Here UGV is deployed with the facility of imaging the payloads so that it may form a 2-dimensional map of its surrounding and identify the position which is known as localization. In addition to this, UGV consists of a wireless camera that will capture some of the pictures to process whether the UGV is in the same environment or in different environment and will update the base station using the feature of IoT.

In section I, reader will find the basics of unmanned ground vehicle and the concept of internet of things. Section II presents the detailed literature review to discuss the current state of the art approaches. The prototyping along with essential number of components is mentioned in section III. Furthermore, the simulation results are demonstrated in section IV. Lastly, one may find the comprehensive research simulations in section V. Here in this section, IoT and SLAM based results are discussed in a fine way. Future directions are discussed under the section VI.

2 Literature Review

There are several research contributions in the stream of computer vision and control where researchers demonstrated the lane detection with and without any marked paths [3]. These techniques are mostly used for autonomous vehicles [4-5]. Since for acquiring the data on IoT one must interface the sensors with this UGV. This will assist the UGV to follow the path with collision free feature [6]. In addition to this, it has computer vision facility that will capture the images and guide the UGV to take possible decision for following the path successfully. Mostly these algorithms are based on Gabor wavelets and on texture base approaches [5-6]. Some of the researchers also used stereo vision approach too such that high tech sensors to detect the curbs [7].

Path following is one the tasks that is defined as searching the basic actuation based on sequence series that will enable UGV to track the path and reach at specific target. Researchers have demonstrated this phenomenon in terms of 2-dimensional mapping [8]. In the list of sensors and electronic components, one may find GPS sensor, velocity meter, thermometer, and manometer etc. whereas researchers have also recommended to utilize sonar and camera-based vision feature too to recognize the hurdle and follow the path autonomously [9]. The identification of location is based on image occupancy grid locations technically [10]. For basic understanding, it is to share that the path or image space is assumed as one of the functions among autonomous UGV and image coordinate system to find the net distance to be travelled. While executing such strategies, researchers mostly proposed the common assumption that stated that the UGV will always begin and travel the distance on a flat ground but in real it is not the case [11-12]. The behaviour of such UGVs have been studied and concluded that such UGVs can follow path from cartesian domain with come way points conveyed to them through computer vision which is one the most recommended method [13]. These path planning approaches have been divided into two categories such that parallel operation and common feature extraction that enable UGV to recognize the path [14]. While studying the literature review, there are some of the contributions that proposed two common methods for hierarchical path planning i.e., fast localization and Image space verification-based localization [15]. Some researchers have proposed trajectory tracking [11] and it is observed that in contrast with image space verification method the fast localization produces less efficient results [15].When UGV is following the path and has an intension to reach at point, many researchers either proposed Kruskal's or Dijkstra's algorithms to compute the shortest path. Though these algorithms are complex to manipulate [16]. These autonomous vehicles either ground, aerial or underwater vehicles are now featured with IoT and computer vision facility [17-19]. Researchers while implementing various algorithms, have used one technical term of disparity that refers to single dimension displacement corresponding to the stereo image, and this is related to the distance of an observed obstacle [20].

In some of the publications, the main factors are computed using radon transformation using central slice theorem [21] and performing visual odometry that helps in producing the 3D motion of the vehicle [22].

The main aim of these algorithms is to identify the features of interest (FoI) in each frame and derive the rigid body transformation that can be best aligned with the fed features over time. While UGV is following the path, the visuals are changing rapidly hence one may find the Harris corner algorithm being fused to detect the instant changes in features and compute the resilient changes.

3 Methodology

The main aim and objective of this manuscript is to propose an IoT-enabled autonomous unmanned ground vehicle (UGV) that plans path and follow it with the feature of collision avoidance using SLAM. In addition to this, the proposed UGV starts travelling from a fixed station and end up to its goal by capturing some of the pictures to correlate whether it is in a friend's zone or an enemy's zone. While following the path, it has additional capability to update the base station about the parameters such that temperature, altitude, pressure, humidity of its surroundings including the detection of any hazardous gas. Thus, to prototype such an IoT-enabled Autonomous UGV following hardware components are required:

- Arduino UNO Microcontroller
- Wireless HD Camera
- L293D H-bridge Circuit
- DC Servo motors
- LiDAR V3 sensor
- ESP8266 wi-fi shield
- DHT-11 temperature sensor
- BMP-180 Pressure and altitude Sensor
- GPS Module
- MQ-2 Gas sensor.
- Frame of UGV

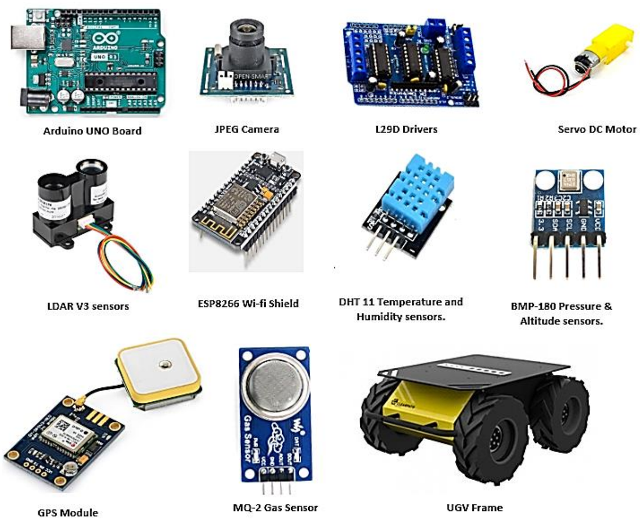


Fig. 2. Components to prototype IoT-enabled Autonomous UGV

These above components are also shown in figure 2. When the UGV is turned on, it will always follow one standard procedure that is divided into three phases as mentioned below:

- Phase I (Path Planning & Mapping using SLAM)
- Phase II (Obstacle Avoidance)
- Phase III (Updating from surroundings using IoT frame of work)

In phase A, IoT-enabled UGV starts from rest and starts travelling to reach at specific coordinates i.e., x *and* y values. The embedded LiDAR sensor will compute the distance and simultaneously checking for any obstacle in between its path. This data will be given to Arduino microcontroller that will compare again and again with the already mentioned coordinates for checking whether the UGV is arrived at goal or not. In simple words, the 4 motors will be driven through the readings computed through LiDAR V3 sensor and it will simultaneously be taking care of hurdles as well.

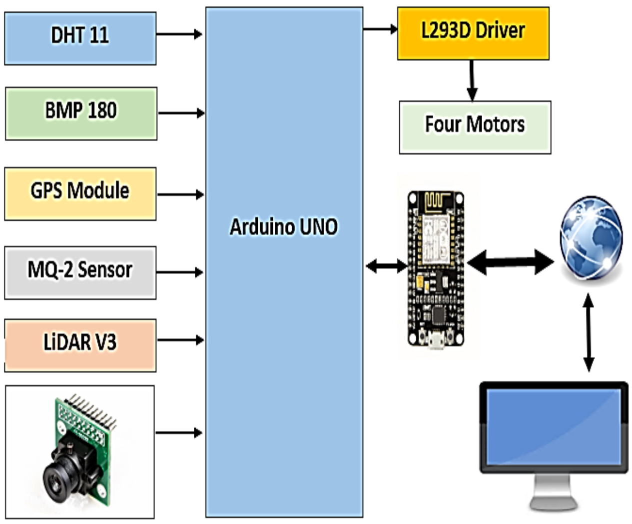


Fig. 3. Basic Block diagram for proposed IoT-enabled Autonomous UGV

Within the programming, there is an equation of two-point distance implemented as shown below:

$$d^2 = ((x_f - x_i)^2 + (y_f - y_i)^2) \quad (1)$$

The block diagram shown in the figure 3 describes the entire phenomenon. The coordinates will be given to the system through IoT platform and UGV will start the drive. During path following it will capture the images using JPEC Camera which will be processed to take decision whether it is in the familiar region or in strange one. Moreover, the LiDAR sensor will help to avoid the collision. Rest of the sensors will be sensing the parameters and provide to Arduino which will send to a static IP for display. For reader to understand the entire process, the implementation has been described in few steps as mentioned below:

- Step 1: The distance will be calculated by providing the x and y coordinates to the system.
- Step 2: This distance will be then converted into number of rotations to achieve the target; this is executed using the LiDAR Sensor. It also shares the instants where the UGV must avoid the collision with any obstacle.
- If there will be any sudden obstacle, LiDAR will help to compute the distance again and will stimuli the IoT-enabled Autonomous UGV to travel at an alternative path.
- During the drive, the entire parameters are shared on one static IP for the monitoring of people at base station.

For the case of intrusion, it is proposed that whenever LiDAR detects any hurdle it will re-calculate the distance from different side by turning the UGV at 90^{o} degrees and move a 1-meter distance back to avoid the collision. In this way, it can easily get the optimum path.

4 Results & Discussion

After prototyping the IoT-enabled autonomous unmanned ground vehicle it has been sent for multiple drives to check the parameters of the surroundings. The results for all sensors are well acquired and sent to static internet protocol (IP) as shown in the figure 4 and 5.

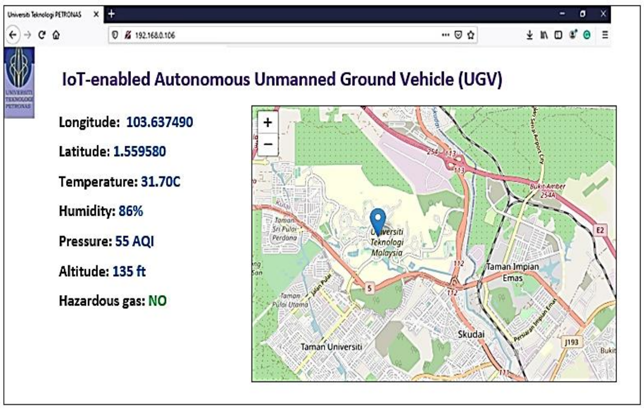


Fig. 4. Result of all sensors on static IP with No hazardous gas.

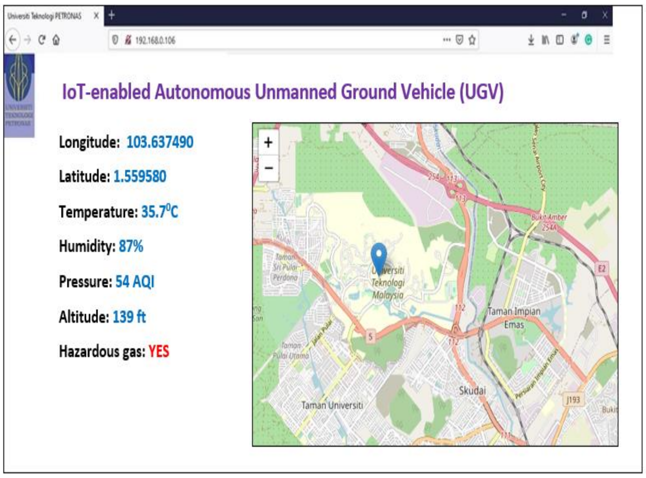
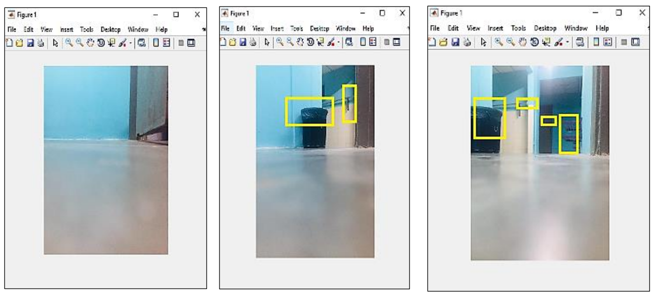


Fig. 5. Result of all sensors on static IP with hazardous gas.

In above figures 4 and 5, one may see the data acquired form all sensors at static internet protocol. The Longitude and latitude readings in above pictures shows the location of Universiti Teknologi PETRONAS, Malaysia along with the current readings of temperature, humidity, pressure, altitude and status for hazardous gas detection. In figure 4 and 5 you can see the difference in readings. Moreover, the IoT webpage has been code in a way that it also accesses the google map where the pin location of Universiti Teknologi PETRONAS, Malaysia.

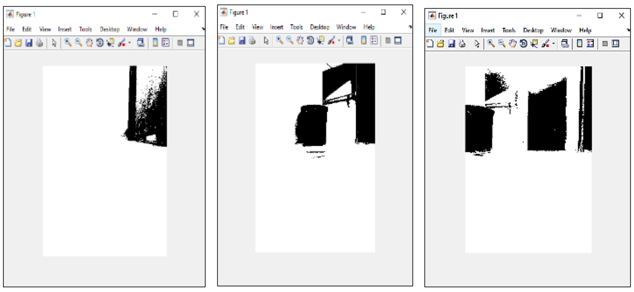
The proposed IoT-enabled UGV starts following path and taking the images through JPEG camera interfaced with Arduino uno controller. These images will be correlated within the saved pictures within the SD card using MAT-UNO application embedded within proposed microcontroller as shown below:



(A) (B) (C)

Fig. 6. Response of Correlated RGB Images

In above captured images one may see that our proposed IoT-enabled UGV is capturing the visuals and detecting the objects with bounded box in yellow colour to conclude whether it is in friend's zone or in enemy's zone. Moreover, these above three sub-images are converted to binary form to measured threshold values and compare it with the already saved images. One may see such binary images in figure 7.



(A) (B) (C)

Fig. 7. Response of Correlated binary Images

Since the provided x and y coordinates are given to Arduino UNO through IP it will start implementing the SLAM Principle and will compute the distance value as per the equation (1). The results are computed using serial monitor of Arduino IDE software as shown below in figure 8:

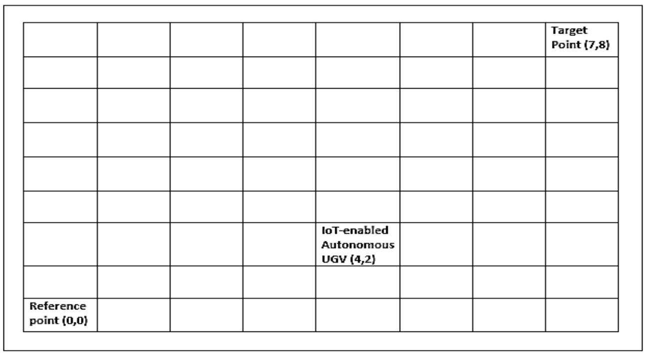


Fig. 8. Planning of Path using SLAM Algorithm

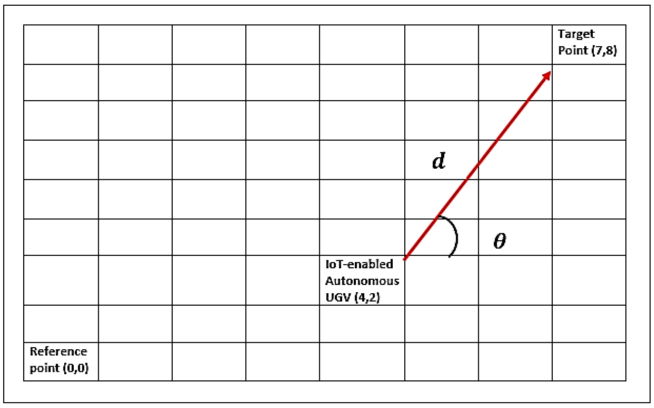


Fig. 9. Illustration of distance vector using SLAM Algorithm

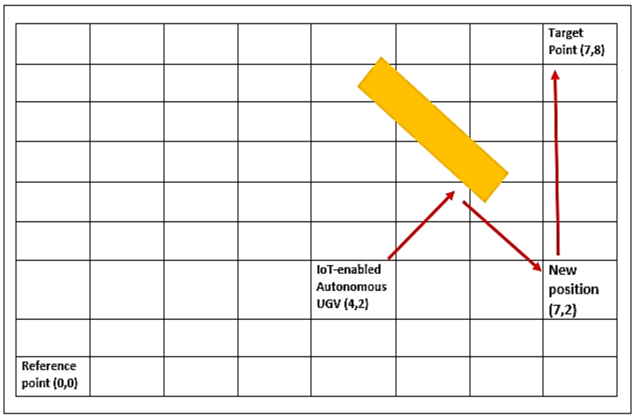


Fig. 10. Illustration of distance vector in case of obstacle.

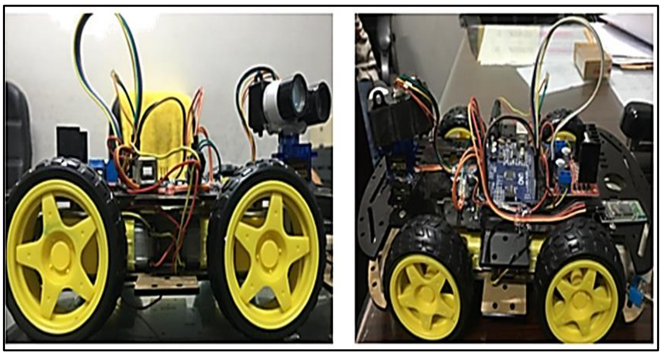


Fig. 11. Final Prototype of IoT-enable Autonomous UGV using SLAM

5 Conclusion

Prototyping an IoT-enabled autonomous UGV for path planning and obstacle avoidance with an additional feature of acquiring the data of essential parameters from its surrounds is presented in this paper. Such type of product can be used in any of the 4-dimensional space i.e., dull, dirty, dangerous, or difficult environment. For mapping and localization, the proposed UGV has been designed by programming the SLAM algorithm that takes x/y coordinates as an input from LiDAR sensor and plan the path accordingly as highlighted in the figures from 8 to 10. Additionally, it senses the environment and acquire the essential data i.e., temperature, humidity, pressure, GPS location and detection of hazardous gas. This entire data is being displayed on a static IP using ESP8266 wi-fi shield. These features make this prototype one of its kinds. The proposed SLAM algorithm provides a value added and novel contribution when it is being fused with IoT feature. This prototype is one of the examples of internet of robotic things (IoRT). The control of UGV is autonomous and robust as per the provided results if and only if the targeted coordinates are provided using

IoT. The proposed UGV has an ability to perform the surveillance in both indoor and outdoor environments.

6 Future Recommendation

The main limitation so far observed is the latency in reaching the targeted coordinates and this is because of the instability of internet connection. The drive is not that aggressive and takes unnecessarily huge time for short tasks. Thus, authors are intended to work on the proposed algorithm of SLAM and further design of IoT feature to fasten the execution of tasks i.e., path planning and updating the data of essential parameters as well.

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Author Contributions

Ghulam E Mustafa Abro and Mujaheed Saleh Abdullahi were responsible for idea and conceptualization.

Jayasankari Ganasan and Mujaheed Saleh Abdullahi performed the data analysis.

Ghulam E Mustafa Abro drafted the manuscript.

Sumayema Kabir Ricky critically revised the manuscript.

Literature review was performed equally by all the authors.