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VISION-BASED MOBILE ROBOT NAVIGATION FOR SUSPICIOUS OBJECT MONITORING IN UNKNOWN ENVIRONMENTS

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Abstract

This study presents the development of mobile robot navigation for detecting suspicious objects in unknown environments. This mobile robot control system combines camera vision and wireless communication. The suspicious object is detected with a camera that is equipped with a metal sensor and gas detection. The movement of the mobile robot can be monitored by GUI from the monitoring station. The result shows the mobile robot can be operated in multi-area tracks such as tiled track, soil track, asphalt track, and a paved track. The reliability check of various trajectories has not been done by previous studies. Moreover, the mobile robot is capable of great variations of movement, such as forward, backward, right turn, left turn, right oblique 45 and 135 degrees, as well as left oblique 45 and 135 degrees. The XBee receiver and transmitter of the mobile robot can be removed in the maximum distance area of 150 meters. The performance of the camera in detecting a suspicious object at 10 degrees of horizontal and vertical are 10 to 200 degree and 0 to 100 degree, respectively. The monitoring for suspicious objects can be conducted on objects containing metal and gas with the detection distance of 0.11 m and 480 m up to 805 ppm.

Keywords: Mobile robot, Navigation, Vision-based camera

1. Introduction

Mobile robot navigation is a challenging task in the study of robotics. Some of the problems in path planning for mobile robots include how to manage camera vision-based camera tracking, avoid obstacles, as well as save time and energy in reaching the desired object. Autonomous navigation in an unknown environment is the most principle issue for the development of mobile robots. Algabri et al. [1] conducted a comparative study on four different aspects, namely path length, time spent, energy consumption, and the average velocity of mobile robots through soft computing programming. Mahdi et al. [2] used a reward function to know the actual distance and the obstacle size and shape, and then combined Markov decision and fuzzy interference system to find a real-time of optimal path planning and ensure the humanoid robot to conduct unknown environment monitoring. Several factors need to be considered, i.e., the coverage area, exploration, surveillance, missions on finding the objects while avoiding obstacles within the robot's constraints in order to accomplish efficient mobility in unknown environments [3, 4].

Furthermore, Marija and Ivan [5] implemented a robotic operating system and validated on the 3D simulator for mobile robots. Tihomir et al. [6] used several techniques to control a mobile robot. One of them is by a mobile inverted pendulum, which is used to move and control a mobile robot motion, through estimating one-step ahead to solve several navigation problems instability, sensor data processing, and the accuracy of the actuator motion.

Arvanitakis et al. [7] stated that the mobile robot navigation to track unknown environments through a goal robot is accomplished by a magnetometer for inferring orientation and limited-range viewfinder. In addition, Masehian et al. [8] developed a team of heterogeneous mobile robots with limited sensing capabilities that were capable of mapping unknown environments through hierarchical architecture and a new unified technique, as well as providing motion techniques and path planning using several sensors as the robot’s equipment.

Furthermore, Hank and Haddad [9] solved a navigation problem for a mobile robot aimed to perform an emergency task in unknown environments through a hybrid approach. Bakdi et al. [10] applied the two-Kinect camera for a two-wheeler to achieve off-line optimal execution and path planning through the vision system by implementing a Genetic Algorithm through a smart environment to achieve a mobile robot localization of estimates for robot pose using real-time measurements [11, 12].

In order to examine the eigenvalue effect on the computational cost, simultaneous mapping and localization are conducted [13]. Khairudin et al. [14] used a region of interest detection method to find the object. On another occasion, Marinho et al. [15] studied the classification for localization using omnidirectional images for rejecting options, which evaluated machine-learning techniques and consolidated feature extractions. Lai and Su [16] used Kinect RGB-D mapping combined with a neural network to support mobile robot development in obtaining the indoor position localization, while Yamanaka and Morioka [17] proposed robot navigation through simplifying the map with a novel SLAM algorithm by referring to Fast SLAM and image matching. Finally, Torrico et al. [18] developed a model controlling a mobile robot, which used finite state machines as the controller for control of mobile robots.

The mobile robot equipment used hybrid vision-based navigation to achieve both indoor and outdoor environments [19]. The robot vision was based on a single camera. Khalid et al. [20] proposed a mobile robot with a map base by using stereo vision to achieve navigation tasks.

Based on previous studies, there has not been much research on mobile robots aimed for finding suspicious or dangerous objects in unknown environments. The suspicious object in question may

The suspicious object in question is an object containing metal and gas in a single unit. The robot developed in this study provides a significant contribution, because not only the motion can be controlled using a remote control, however, it can also be manipulated through the GUI menu at the home monitoring station. This means that even without the remote control, the robot can still be controlled by using the input button in the GUI. In addition, the study also managed to display the size of the metal and gas object on the GUI display as the result of applying the metal and gas sensors in the monitoring activity.

Therefore, this study presents the development of mobile robot navigation for monitoring and detecting suspicious objects. This paper also presents the robot tracking capability in various unknown environment areas with a vision-based camera. The long-distance communication between the transmitter and receiver of the mobile robot is achieved through media monitoring on the GUI. Moreover, this study also compares the mobile robot responses when tracking an unknown environment area with various degree of slope. This aspect has not been widely discussed in previous studies. In this study, mobile robot testing has been carried out in multi-area, such as tiled track, soil track, asphalt track, and a paved track. This paper also presents the ability of a mobile robot to perform variations of movement namely forward, backward, right turn, turn left, right oblique 45 and 135 degrees, left oblique 45, and 135 degrees. There are many variations of movements to find suspicious objects containing gases and metals. The description of the mobile robot is presented, followed by the control technique used, submission of tracking result of unknown environments to detect and search for an object, and a result of detection of metal and gas objects. The results show the mobile robot can track the route with a slope of 34 degrees horizontally, the mobile robot can be controlled within a maximum distance of 150 m. The camera vision in this mobile robot can detect an object in various angles. The suspicious objects that can be detected are objects that contain metal and gas.

2. Mobile Robot Navigation

Figure 1 shows the experimental setup of the mobile robot used in this work. This section presents the mobile robot used in this study. The rig consists of several parts: a module of mobile robots with four wheels, sensor parts and a processor. The mobile robot is designed in the form of a beam. The camera is topped with the aim of detecting any suspicious object and can reach a wide and remote viewing power. In addition, the repeater antenna is mounted to the right and left position of the camera. The metal detection sensors and gas detection sensors are placed in the front position of the robot in order to facilitate the detection of suspicious objects.

The camera used is Foscam FI8918W, while the metal sensor used is Inductive Proximity. The gas sensor used is Gas sensor MQ-136 Hydrogen Sulfide, while the serial communication employs noncable equipment, namely XBee S2B Pro and USB Wi-Fi TL-WN8200ND. In addition, the router used Tent N300, while the monitoring view of robot movement was done by using GUI Visual Studio 2015, which provided access to the operator, user, or monitoring station. Belt wheels were used on the mobile robot to track various unknown environments.

The gas sensor system (MQ-136) and Proximity inductive metal sensor are wired to Pin.PF1 and Pin.PD1, respectively. The detailed specifications of the mobile robot can be seen in Table 1.

Fig. 1. Experimental setup of mobile robot.

Table 1. Parameters of mobile robot specifications.

Components	Specifications
Power supply	Powerbank 14000 mAH 5VDC Lipo Batery 3S 2200 mAH 12 VDC
Data processor	Arduino Mega 2560
Actuator	Motor DC 7.2V
Camera	Foscam FI8918W
Router	Tenda N300
Wireless communication	XBee S2B Pro USB Wi-Fi TL-WN8200ND
Sensor	Gas Sensor: MQ-136 Hydrogen Sulfide Metal Sensor: Inductive Proximity
Step-down	Step-down Variable with 7 Segment
GUI	Visual Studio 2015
Bodyframe	Acrylic with the thin of 3mm
Motor driver	Type L298N
Body size	
Height	0.30 m
Width	0.25 m
Length	0.33 m

A precision interface circuit uses an Arduino mega microcontroller for data processing and image processing. The control system used in this study is object-oriented IF-THEN logic. The algorithm and communication diagram system used between the mobile robot and home monitoring in this study can be seen at Figs. 2 and 3 respectively. The algorithm began with XBee identification, Xbox controller and IC camera. The objective was to operate the mobile robot to search for a suspicious object.

From the diagram system of communication between the mobile robot and home monitoring via WiFi access points, it can be seen that by setting up the router with a specific IP address, as well as setting up the IP-camera with specific address and connecting it to the router LAN cable allowed the robot to send the image or video image data. From a laptop/PC, the operator can open the connection to get a WiFi signal using the previous router set-up. The next step was opening the mobile robot monitoring application on Windows. Through this application, the operator was able to adjust the IP address setting of the IP Camera.

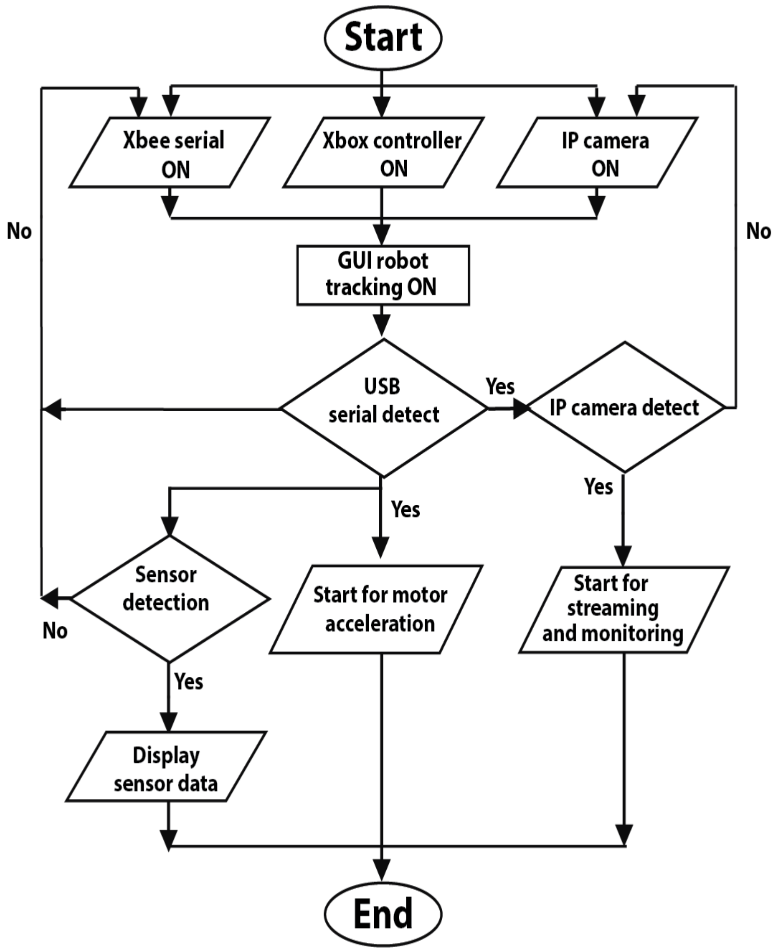

Fig. 2. Algorithm for mobile robot navigation.

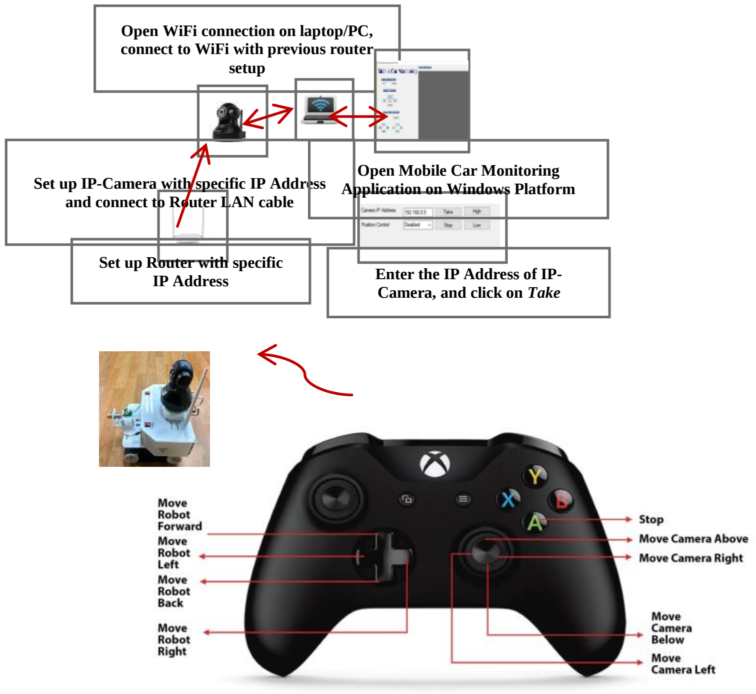

Fig. 3. Communication scheme between robot and home monitoring.

The mobile robot navigation for monitoring suspicious objects is equipped with a camera to observe the surrounding environment that will be displayed in the GUI. The data processor used in this study is the Arduino Mega microcontroller. Wi-Fi signal emitted using a router to a Wi-Fi laptop or a personal computer is used to send the camera scanned image data, as shown in Fig. 3. Serial communication is used to obtain sensor data and motor acceleration movement. Sensor data will be displayed on the GUI window display. Serial data transmission uses XBee so that communication can be done remotely. A mobile robot can be operated using the GUI input button or manually using a remote control as presented in Fig. 3.

The speed of the robot is determined by the linear and angular velocity with V and ω respectively. On the other hand, L, r and R are the distance between the two wheels, the radius of the two wheels, and the distance between the midpoints of the two wheels with the rotation of centre point C, respectively. The linear velocities of V_l and V_r for left and right wheels, respectively, are determined by the relationship between the angular velocity and the radius of the wheel as follows:

$$V_r(t) = \omega_r(t) \cdot r_r \tag{1}$$

$$V_l(t) = \omega_l(t) \cdot r_l \tag{2}$$

From here on, the length of the radius will be referred to only as r because the left and right wheels are the same sizes.

$$\omega_r(t) = \frac{V_r(t)}{r} \tag{3}$$

$$\omega_l(t) = \frac{V_l(t)}{r} \tag{4}$$

When the robot does a rotating motion, the length of the radius from the centre of the rotation of C and the midpoint of the two wheels is measured as R, the rotational speed at each point of the robot is always the same (a robot is a rigid mechanical system), therefore, Eqs. (5) and (6) are used to calculate the rotational speed of the robot.

$$\omega(t) = \frac{V_r(t)}{R + L/2} \tag{5}$$

$$\omega(t) = \frac{V_l(t)}{R - L/2} \tag{6}$$

Based on Eqs. (5) and (6), the rotational speed of the robot can be calculated by simplifying the linear velocity of the robot wheels.

$$\omega(t) = \frac{V_r(t) - V_l(t)}{L} \tag{7}$$

Meanwhile, the radius of R can be found as follows:

$$R = \frac{L(V_r(t) + V_l(t))}{2 \cdot (V_r(t) - V_l(t))} \tag{8}$$

It can be seen in Eq. (8) that the radius of the circular path is inversely proportional to the difference in the speed of the robot wheel. The smaller the difference between the two speeds of the wheel, the longer the radius of the instantaneous circle is. In other words, the R formed by the robot path may be longer or shorter according to the speed. As the rotating motion of the robot is at the centre of the axis (R = 0), based on equation (8), the speed of the two wheels must be opposite ($V_r = -V_l$). Based on Eqs. (7) and (8), the linear velocity of the robot can be calculated using the equation $V(t) = \omega(t).R$ substituted to:

$$V(t) = \frac{V_r(t) + V_l(t)}{2} \tag{9}$$

To simplify Eqs. (7) and (9), the following calculation can be done on vector matrix equation.

$$\begin{bmatrix} V(t) \\ \omega(t) \end{bmatrix} = \begin{bmatrix} 1/2 & 1/2 \\ 1/L & -1/L \end{bmatrix} \begin{bmatrix} V_r(t) \\ V_l(t) \end{bmatrix} \tag{10}$$

Equation (10) above essentially shows the relationship between the linear velocity of the robot wheels and the robot's angle velocity.

In practice, the algorithm used for the communication between robot and monitoring station was applied in several stages. First, in the home monitoring application, a thorough check was done on the connection of the XBee serial and Xbox controller, as well as the camera's connection to the Wi-Fi. This connection would allow the home monitoring application to run and start the streaming process via Wi-Fi, while the data from serial data would be transmitted through XBee. Secondly, the data from the XBee series sent by the Arduino robot were used in sensor readings related to metal and gas. Thirdly, the home monitoring application sent serial data signal to drive the acceleration of the DC motor based on the specified target. Next, the process of sending serial data is accompanied by the process of sending data through the Wi-Fi. The device used in the process of sending data by Wi-Fi is the FOSCAM FI8910W IP camera working as streaming and visual monitoring of the surroundings. This algorithm is unique since it modifies home monitoring applications by streaming based on Wi-Fi data transmission through the IP address in the IP camera. Thus, it will respond more quickly and provides more consistent results of streaming. At last, it has two modes of resolution-high and low resolutions-that are used in accordance with the resolution of the used IP camera.

3. Results and Discussion

This study presents the performance of mobile robot navigation to monitor suspicious objects in unknown environments. In the first stage, to determine the location of a suspicious object, the mobile robot navigation gets instructions to automatically walk towards the target. The mobile robot is controlled using the input button at the GUI or remote control from the home monitor. As shown in Figure 2, if the sensor detector successfully finds a suspicious object, the system will show the number of objects either from a metal sensor or gas sensor. Moreover, when the sensor does not successfully detect a suspicious object, it returns to the XBee serial identification stage as shown in Fig. 2. While searching and travelling to a suspicious object, the mobile robot is controlled through Wi-Fi.

This study presents the image processing based on a camera-based vision sensor to support a tracking control of a mobile robot. In this study, the image processing is started with video streaming to access permission of the IP Camera. Subsequently, the system will initialize buffering before showing the images. Thus, the GUI at the home monitoring system can access and receive the video images.

The next step of image processing is creating an array of images and rebuilding the Jpeg image for the buffering process. The system will find the top, bottom parts of the images, and then continue to create images to be displayed in the App with the GUI system.

The performances of mobile robot navigation to search for a suspicious object are presented in its ability to monitor in various environments. During the search, the Foscam FI8918W camera always scans the environments that it passes by. Figure 4 shows the results of the Foscam FI8918W scan with various control distance from a laptop/personal computer. It is noted that when the Foscam FI8918W camera is integrated with the robot movement, the camera can scan all the environments passed by the robot. The camera works similarly to human eyes as it can scan the surrounding objects at a radius of 2 to 54 meters.

(a) Distance of 2 meters.

(b) Distance of 54 meters.

Fig. 4. Images taken by mobile robot in various distances.

The performance test for detecting suspicious objects is done by setting the camera in both horizontal and vertical angles, so it may scan objects within 10-200 degree of horizontal and vertical directions. Based on the test, it is found that the camera works very well in all unknown environments. To present another environment or to identify a different environment than the camera can detect, the images or video images are displayed at GUI through home monitoring. During the test, it is found that the mobile robot can recognize different environments.

Figure 5 presents the distances within the range of scanning that are taken by the mobile robot navigation to search for a suspicious object. It is noted that at the distance of over 50 meters, the mobile robot finds no obstacles in scanning the unknown environments.

The performance of serial transmitter data using XBee is presented in Table 2. It is noted that at the distance of 1 to 125 meters between the monitoring station and the mobile robot, there is no delay on mobile robot movement and the monitor shown by GUI. At a distance of more than 130 meters, there is a delay that varies between 2 to 6 seconds. However, the robot cannot be monitored and operated by the monitoring station if the distance is more than 150 meters.

(a) 4 meters.

(b) 28 meters.

(c) 42 meters.

(d) 58 meters.

Fig. 5. Inter-relation among signal strength, the distance of monitoring operator, and mobile robot navigation at 4 by 4 scale signal capacity.

Table 2. Covered distances monitored from the monitoring station.

Distance (m)	Data delivery	Response of motor movement
1 into 125	Swift responses	Motor is rotated by PWM when the button is pressed
130	Slow response	Motor is rotated PWM, and there is a 2 seconds delay when the button is pressed
135	Slow response	Motor is rotated PWM, and there is a 2.2 seconds delay when the button is pressed
140	Slow response	Motor is rotated PWM, and there is a 3 seconds delay when the button is pressed
145	Slow response	Motor is rotated PWM, and there is a 6 seconds delay when the button is pressed
150	No response	Motor does not spin; the connection fails

The speed that the mobile robot navigation can reach and the distance that it can take vary greatly based on the location and environment. Figure 6 shows that some types of track accelerate the robot speed when it is tested in the same PWM value given to the DC motor as the mobile robot actuator. It is found that the average velocities of the mobile robot in the ceramic tile track and concrete track are 0.197 m/s and 0.157 m/s. With the same PWM supply on the DC motor, the mobile robot goes faster in the ceramic tile track than in the concrete track.

During the performance test, the mobile robot navigation movement performed a variety of movements, for example forward, backward, right turn, left turn, right oblique of 45 and 135 degrees, left oblique of 45 and 135 degrees. The movements can be done with the variation of PWM input of 65 to 225 with different allotted time on each PWM (varies from 1 to 7 seconds). Figure 7 presents the results of a mobile robot navigation performance test with various motions. It is shown that the mobile robot navigation can move well. It can move forward and backward, turn right and left, in addition to turning right oblique of 45 and 135 degrees, as well as left oblique of 45 and 135 degrees. However, the robot performs a backward motion differently after performing normally in the first two seconds.

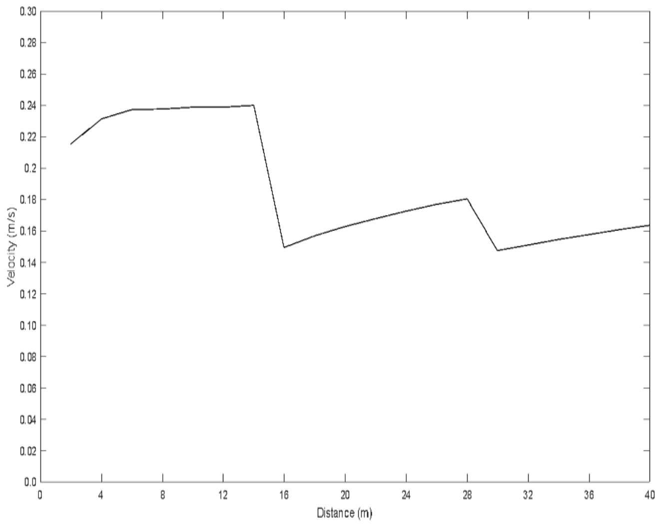

Fig. 6. Inter-relation between unknown environments and speed.

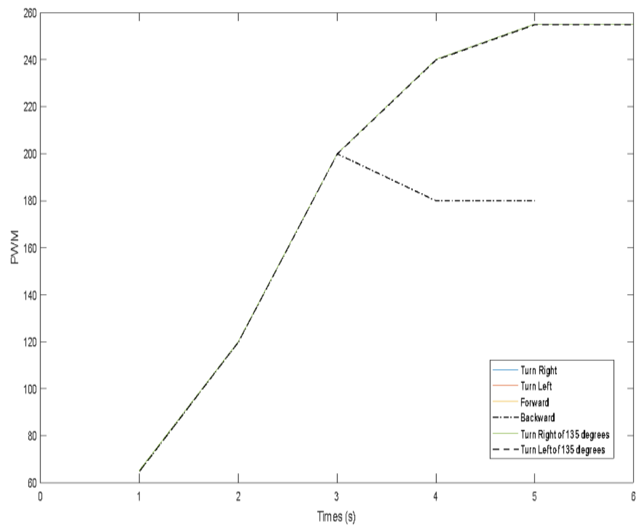

Fig. 7. Mobile robot navigation performances in various motions.

In the next performance test, mobile robot navigation moves to various directions in sloping areas. At first, the performance test conducted in slope surfaces is set in 2 degrees to 34 degrees of horizontal angles, which are presented in Fig. 8. The mobile robot navigation can move faster on the track with a smaller degree of slope angle than on a steeper track. It is noted that the steeper and higher the surface angle is, the slower the robot moves.

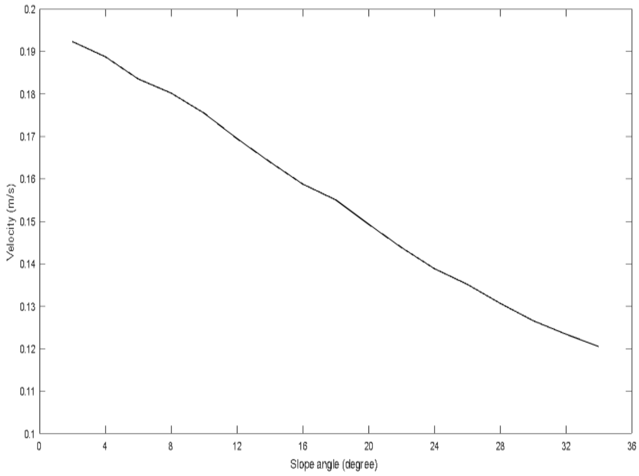

Fig. 8. Inter-correlation between slope angle of tracking area and velocity.

The performance test on the capability of tracking in unknown environments is conducted in various track, namely tiled track, soil track, asphalt track, and a paved track. The robot is assessed in performing some movements, i.e., forward, backward, right turn, left turn, right oblique 45 and 135 degrees, as well as left oblique 45 and 135 degree. The ability of the mobile robot navigation to move in the same performance on all types of tiled track, soil track, asphalt track, and a paved track. The robot shows the same performances for every forward, backward, right turn, left turn, right oblique 45 and 135 degrees, left oblique of 45 and 135-degree movement as shown in Fig. 7.

It is noted that in all types of tracks, the robots can perform well all variations of movements such as forward, backward, right turn, left turn, right oblique 45 and 135 degrees, as well as left oblique 45 and 135 degrees, so the mobile robot can reach all parts of unknown environments. In addition, the mobile robot navigation has the same motion abilities to move forward, turn right, turn left, turn right 135 degrees and turn left 135 degrees on all types of unknown environments. Although the robot moves backwards differently, it is capable of moving well on all tracks from the beginning to the first two seconds. In other words, the performance of the mobile robot navigation is represented by the accuracy test on the sensor system. The MQ-136 Hydrogen Sulfide gas sensor can detect the presence of Liquefied Petroleum Gas (LPG) and smoke. The amount of gas that can be detected by the system in this study is 480 into 755 ppm and 480 into 805 within the range of 10 meters for LPG and smoke respectively. Meanwhile, the gas with a ppm value smaller than 60 can only be detected in a relatively small radius. It is noted that the gas that can be detected by the mobile robot through the MQ-136 Hydrogen Sulfide sensor is 480 ppm in minimum. Thus, it can be said that the mobile robot, which is aided with MQ-136 Hydrogen Sulfide sensor, can accurately detect the emergence of gas.

The performance test on the mobile robot navigation shows that it can detect metal part of the suspicious object with the Proximity Inductive metal sensor. The accuracy of inductive proximity sensor metal detection is shown when detecting in a straight angle as well as 45 and 90-degree oblique. It can reach up to a maximum of 0.11, 0.06 and 0.04 meters respectively. The Inductive Proximity sensor of metal detection is more accurate when the suspicious object is in a straight angle (180 degrees).

The performance test on the mobile robot navigation with camera-based vision measures its capability of determining a location of a suspicious object, reliability, and range of communication between mobile robots with monitoring station located within the range of 150 meters, tracking ability with various unknown environments such as tiled track, soil track, asphalt track, and paved track in performing a variety of movements such as forward, backward, turn right, turn left, right oblique 45 and 135 degree, left oblique 45 and 135 degree. The test also measures the ability of the mobile robot navigation to accurately detect a suspicious object containing metals and gases. All these capabilities show that mobile robot navigation can track suspicious objects in unknown environments.

4. Conclusions

The development of mobile robot navigation for tracking a suspicious object in unknown environments has been presented. This study reviews state of the art vision-based control for mobile robot navigation to be able to track unknown environments such as tiled track, soil track, asphalt track, and a paved track. The communication between the mobile robot and the monitoring station is through wireless communication (Wi-Fi). The mobile robot performance test has shown that it can perform various movements. The mobile robot navigation is equipped with a gas sensor, namely MQ-136 Hydrogen Sulfide and a metal sensor Proximity Inductive, which function as a tool to search and find a suspicious object containing metal or gas. The mobile robot can move and look for a suspicious object by displaying metal and gas sensor data in real-time.

Nomenclatures

L	Distance between two wheels, m
R	Distance between the midpoints of two wheels with rotation of centre point, m
r	Radius of two wheels, m
V	Linear velocity, m/s
V_1	Linear velocity of left wheel, m/s
Vr	Linear velocity of right wheel, m/s

Greek Symbols

ω	Angular velocity, rad/s

Abbreviations

GUI	Graphical User Interface
RGB	Red, Green, Blue
LAN	Local Area Network
LPG	Liquefied Petroleum Gas
PWM	Pulse Width Modulation

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