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Vision Based Indoor Surveillance Patrol Robot Using Extended Dijkstra Algorithm in Path Planning

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***Abstract* – Vision based patrol robot has been with great interest nowadays due to its consistency, cost effectiveness and no temperament issue. In recent times, Global positioning system (GPS) has been cooperated with Global Navigation Satellite System (GNSS) to come out with better accuracy quality in positioning, navigation, and timing (PNT) services to locate a device. However, such localization service is yet to reach any indoor facility. For an indoor surveillance vision based patrol robot, such limitation hinders its path planning capabilities that allows the patrol robot to seek for the optimum path to reach the appointed destination and return back to its home position. In this paper, a vision based indoor surveillance patrol robot using sensory manipulation technique is presented and an extended Dijkstra algorithm is proposed for the patrol robot path planning. The design of the patrol robot adopted visual type sensor, range sensors and Inertia Measurement Unit (IMU) system to impulsively update the map's data in line with the patrol robot's current path and utilize the path planning features to carry out obstacle avoidance and re-routing process in accordance to the obstacle's type met by the patrol robot. The result conveyed by such approach certainly managed to complete multiple cycles of testing with positive result.**

Keywords — Vision system, indoor surveillance, robotics, surveillance robot, path planning.

I. INTRODUCTION

Patrol robot is a machine with moving mechanism that build up with microchips and sensors to sense the surrounding environment, and report back the situation to a control room/tower. Nowadays the patrol robots have capability to keep data in their memory and some of them even can share their collected data in cloud storage while executing their tasks. There are three categories of travelling mediums for the patrol robots: land based, air based, and water based.

A land based wheeled mobile robot (WMR) use for indoor surveillance patrolling is selected to be discussed in this paper, cover from basic robot driving system to move the patrol robot around the ground, sensory manipulation for the patrol robot to sense surrounding environment and most importantly it does cover obstacle avoidance, path guidance and path planning for the patrol robot to avoid possible collision happen between robot and obstacle.

Vision based indoor surveillance patrol robot discussed in this paper is a security type robot constructed to navigate from one scouting location to a distinct scouting location. Images are captured by the robot's vision system throughout the navigation path and analyzed to report on human intruder incident/ non-intruder incident. Vision based indoor surveillance patrol robot has the advantages of capable to record the patrol scenes and replay the recorded scenes for evidence, in contrast to traditional human patrolling that are not carrying a camera all time. Under the operating cost consideration, positioning several vision based indoor surveillance patrol robot is much lower than hiring the same amount of human security officers to continuous patrolling on a specific indoor environment. Some more the human security officers might overlooked some situation due to tiredness but the patrol robots no.

The android application of non-vision based patrol robot in [1] had embedded various types of sensors on the proposed robot. The constructed robot is well in sensing the patrol areas' surrounding environment condition. Nevertheless, such type of patrol robot is without vision system. Hence no patrolling scenes are being captured and recorded for human intruder/ trespasser analysis and evidence keeping.

A new multi-model integrated scheme with vision sensors and inertial navigation system had been developed by [2] for mobile robot navigation to get rid of the problem of visual data

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inaccuracy during the robots making turns. The developed mobile robot also adopting Mecanum wheels for fixed point turning, making the robot position uninterrupted during the process of turning. The similar multi-model integrated scheme is modified and adopted for the patrol robot in this paper.

One of the most important feature for an autonomous patrol robot is Path planning. This feature allows an autonomous patrol robot to look for the shortest and optimum path to navigate from one location to another location within the robot vision or a charted map. Path planning for mobile robot navigation commonly segregated into some processes parts to lower down the complexity in searching for the feasible path.

Multi-Layer Based on Path Planning System(MLPPS) [3] is one of the lately evolved path planning algorithm used in autonomous vehicle. The algorithm began with supplying the information from laser imaging, detection, and ranging (LiDAR) and Global positioning system (GPS) signal corrected inertial navigation system (GPS/INS) to improve the first bottom layer of local path planning. The data is then passed to second layer of path update arbiter to seek for feasible path that connecting the current local block to another local block. The third upper layer of the algorithm to get the optimal path result is a global path planning algorithm (with A* search capability).

Computer Vision Continuously Mean Shift (CAMShift) and D* Algorithm [4] is another indoor navigation system developed for visually impaired person. The technology of Cameras and Bluetooth beacon were placed to help the visually impaired users to locate and navigate for shortest path to a destined location. Other than this, [5] proposed an indoor path planning navigation algorithm formulated on wireless sensor networks by the trilateration positioning to navigate a mobile robot from one location to another location. Nevertheless, the above proposed path planning algorithms are having their strengths and weaknesses: MLPPS in [3] is good in shorten the path planning dataset, but GPS/INS system is not fit for the usage in indoor environment. In addition, both of the beacon power range sensing methods [4, 5] are hard to implement in a larger operation range.

A current advanced Dijkstra algorithm by practitioners in [6] drew the attention of researchers from the autonomous mobile robot sector to further research. The Dijkstra algorithm [6] main concept is to obtain all of the locations within the navigation map to find the shortest path from a starting location to the destine location. The algorithm outfit the vision based indoor surveillance patrol robot as the typical Dijkstra algorithm able to split the map into two data set sections, the local route and the patrol station. This ease up and minimize the time spend for the vision based indoor surveillance patrol robot in searching the shortest path to reach the destination.

The typical Dijkstra algorithm [6] is unsuitable to be straight forward utilize in the vision based indoor surveillance patrol robot owing to the continuity of the real time charted map that updating based on the situation on the mobile robot faced from time to time. The vision based indoor surveillance patrol robot shall have the capability to create new nodes or adding new alternative path on the safe region for the robot to achieve the obstacle avoidance. Simultaneously, the patrol robot shall be managed to re-route the pre-define route depend on its recent location to the targeted location while meeting inevitable obstacle.

Consequently, an extended Dijkstra algorithm in accordance with the typical Dijkstra algorithm in [6] is developed in this paper and implemented into the vision based indoor surveillance patrol robot to handle the issues raised in the previous paragraph, which authorize the patrol robot to seek for the optimum path, get to the target destination and return to home position from repetitive tests in a random open/close door, arrangement of obstacle and size of the obstacle. It achieved the desired path planning target with accuracy as higher as 90 %.

The paper structural is arranged in the following manner: Section II will outline the vision based indoor surveillance patrol robot system architecture, section III will discuss about indoor localization and mapping method for the vision based patrol robot, section IV will describe the proposed extended Dijkstra algorithm for patrol robot's path planning and section V will presents some experimental results and in depth performance analysis. Finally, in section VI, some conclusion and future developments will be drawn.

II. Vision Based Indoor Surveillance Patrol Robot System Architecture

The vision based indoor surveillance patrol robot system architecture is shown in Fig. 1. This System architecture is divided into two parts, one part is computer and the another

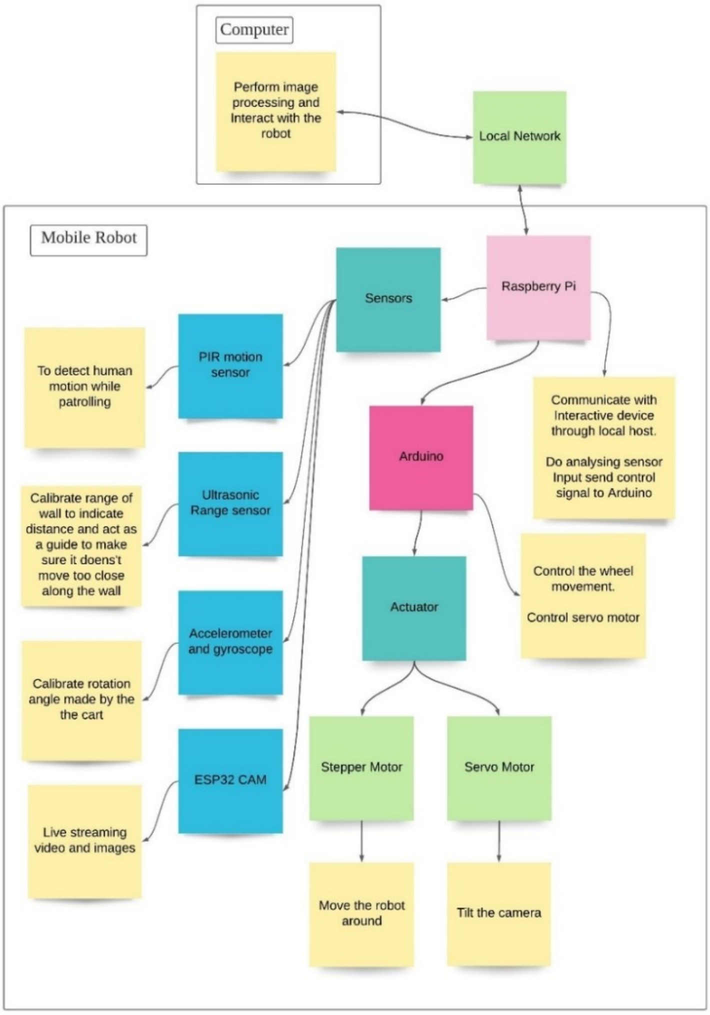

Fig. 1. Vision based indoor surveillance patrol robot system architecture.

part is on mobile robot platform. The computer will handle heavy task such as image processing and path planning, the mobile robot equipped with two control unit which is a Raspberry Pi for sensor data analysis and an Arduino as the stepper motor controller. Both of the onboard control unit will communicate through serial port. The camera module ESP32CAM captured live stream images and send them to the computer to perform image processing on path planning and human intruder detection. For the sensors, the system has passive infrared (PIR) motion sensor to detect human object motion, ultrasonic sensor placed on the left and right side of the patrol robot for collision avoidance (obstacles, wall and cliff detection), Accelerometer and gyroscope as IMU module to identify the mobile robot orientation and moving direction within the map.

A. Sensors

The primary sensor utilized on the vision based indoor surveillance patrol robot is the vision tool. The vision tool contributes data images for the decision making of path planning and human intruder detection. ESP32CAM was chosen for the vision tool due to the capability in capturing images and videos data with about 2 Megapixel of resolution. The second sensor type utilized on the vision based indoor surveillance patrol robot is the motion sensor. Motion sensor is adopted to reveal human object's motion throughout the time of the robot patrolling in action. The detected motion will signal the motion detection alarm to alert those security officers in the command post. HC-SR505 mini PIR motion sensor was chosen, for its within three meters' range of induction distance. The third sensor type utilized on the vision based indoor surveillance patrol robot is the range sensor. Range sensor is adopted to forbid the patrol robot from banging to the obstacles, wall or cliff during the patrol in action. HC-SR04 ultrasonic sensor was adopted, due to its precise detection range (from 0.02 m - 4.00 m). The fourth sensor utilized on the vision based indoor surveillance patrol robot is the Inertia Measurement Unit (IMU). IMU is a type of localization sensor system operate in conjunction with digital motion processing for indoor positioning. IMU positioning estimation method is depending on the acceleration, orientation and angular rates of the patrol robot. MPU-6050 accelerometer and gyroscope were chosen, due to it comprises of good sensitivity and fine accelerometer scale (3-axis gyro sensor with sensitivity of 131 LSBs/dps second and 3-axis accelerometer with scale from ±2 g up to ±16 g).

B. Microcontrollers

Microcontrollers are required to communicate with multiple sensors, preprocess the gathered images and sends to the Computer. It also controls the actuators based on the predefined map data and routing the robot by sending command to the actuator's controller. Two types of microcontrollers are adopted in the vision based indoor surveillance patrol robot. They are Raspberry Pi and Arduino. The latest Raspberry Pi 4B is chosen to communicate with interactive devices through local host, analyze sensors input and passed the control signal to Arduino. Arduino ATMega328p is used to fit those actuating tasks, including control the wheel of the robot movement (Stepper Motor Driver and stepper motor mount on patrol robot's wheels) and control the servo motor for tilting the ESP32CAM camera.

C. Actuators

Two types of motor actuators adopted in the proposed vision based indoor surveillance patrol robot. The first type of motor actuator is the stepper motor (NEMA 17HS4401 bipolar stepper motor) attached with Mecanum wheels [7], for the patrol robot to be driving around the patrol site. The stepper motor has smallest step size, up to 1.8^{o} per step. The specialty of this stepper motor is the patrol robot can alter the orientation steadily during robot movement without drifting the robot. Stepper motor is with lower speed in compare to DC motor. However, stepper motor able to manipulate high torque, steady at constant repetitive motion and it will not breakdown even though it is occasionally overloading with high current on an attempt to maintain its torque. The second type of motor actuator is the servo motor (SG90 Micro servo), which use to hold and tilt the ESP32CAM to capture the surrounding environment images. Servo motor is a kind of close-loop operated motor that needs not requires additional sensor to pinpoint the motor's direction. The selected SG90 Micro servo has compact motor size and it can be mounted on a miniature robotic arm to hold the ESP32CAM. Both the stepper and servo motors will be control by the Arduino ATMega328p (the onboard actuator controller).

D. Communication Platform

The vision based indoor surveillance patrol robot functions in an indoor environment as if uneven obstacles like furniture, walls, doors and staircases are ordinary in these places. The best method to get the Computer and patrol robot platform communicate effectively among each other is by non-line-of-sight (NLOS) communication method. The communication platform allows the command and data sharing among the computer and the patrol robot. Hence, a 2.4GHz Wi-Fi network with a reachable Wi-Fi router is adopted.

E. Image Processing Unit

Raspberry Pi and Computer are the two image processing units adopted for the vision based indoor surveillance patrol robot. The software used for image processing is the Python programming is the adopted image processing software. OpenCV-python Image processing is the main library in Python programming software for running the image processing tasks. The main image processing tasks for the vision based indoor surveillance patrol robot can be divided into two main parts: First part is on pre-processing, in which the received images will convert into grayscale format and carry out the Gaussian noise filtering [8]. Second part is on post-processing, in which for path planning tasks, the grayscale images received from first part of the image processing task will be analyzed by disintegrate each of the image into two sections and the differences between nearest current path region and the front path region is compared using Canny Edge obstacle detection method [9]. The image pre-processing tasks are not tremendous; therefore, they can be handled by the Raspberry Pi 4B that placed on the patrol robot. The image post processing tasks would be handled by the Computer (the current computer model used is ASUS A556U with Intel® Core™ i5-6200 Processor. NVIdia 980M 12GB RAM). The Computer will carry out the image post processing, execute path planning and updating the virtual 2-Dimensional map (if required).

The salient element in the vision based indoor surveillance patrol robot's path planning is on those images captured by the ESP32CAM, because obstacle detection and obstacle classification are highly relying on them. Apart from that, range sensors that guide the patrol robot to travels in a narrow corridor and the IMU system for complete the localization process within the 2-Dimensional predefined map are crucial too.

III. INDOOR LOCALIZATION AND MAPPING METHOD FOR THE VISION BASED PATROL ROBOT

Robot odometry are important to predict unseen data and estimate optimal parameters for the location and orientation of the vision based patrol robot. Figure 2 shown an odometry layout used to determine the location of the vision based patrol robot in real time, while the patrol robot is navigating.

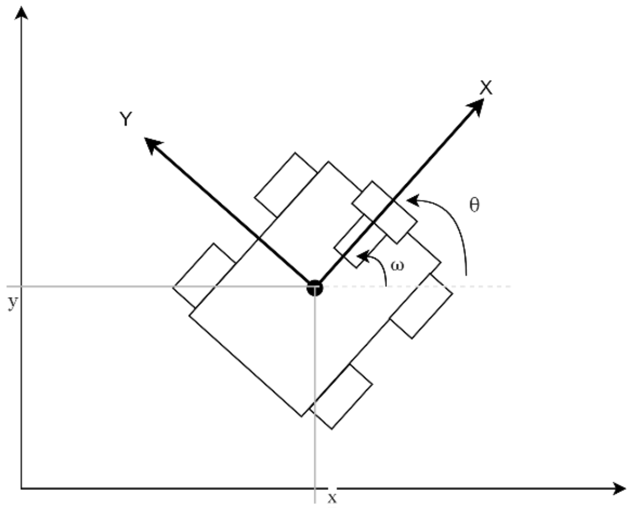

Fig. 2. Odometry.

There are 6 raw data (acceleration and angular velocity for each *x*, *y* and *z*) from IMU will be converted with:

$$Converted\,Value = \frac{Raw\ value}{\left(\frac{65536}{n}\right)} \quad (1)$$

where 65536 is 16 bits' value and *n* is the parameter setting. *n* value for gyroscope and accelerometer are different depend on performance setting, by multiplying acceleration value with gravity value 9.81 m/s^2.

To remove noise, 2nd order butter-worth low pass filter is adopted to filter out noisy signal. By using the angular velocity on z-axis from the filtered value, calculate the yaw's theta:

$$\theta_n = \theta_{n-1} + \omega dt \quad (2)$$

θ_0 are 0, ω is the filtered value angular velocity multiply by the change of time, *dt*.

Accelerometer value is very sensitive and when the patrol robot is moving with constant speed, it tends to have zero acceleration. Thus, the accelerometer value is difficult to adopt for the distance travelled calculation. Stepper motor pulses are adopted to perform the distance travelled calculation. For example: stepper motor pulses to move for a distance of 5 cm which equivalent to 1 Unit distance for each positioning step in this system. Hence an equation is modelled for the distance travelled calculation:

$$pulse = \frac{d}{2\pi r \times step\ angle\ ratio} \quad (3)$$

$$d = 2\pi r \times pulse \times step\ angle\ ratio \quad (4)$$

where d is the distance move, r is the radius of the wheel. In this vision based patrol robot case, the adopted Mecanum wheel radius is approximately 3.75 cm and with a step angle of 1.8° per step, thus $step\ angle\ ratio$ is 1.8/360 = 1/200. Hence, the number of pulses required to move and update the position (d = 5 centimetres away from previous position) is approximately 43 pulses.

The ideal time that taken for the patrol robot to move from one position to another position (d = 5cm distance) are depending on the frequency f_p:

$$t_{d(ideal)} = pulse \times f_p \quad (5)$$

However, in practical world there are uncertainties to be encountered:

$$t_{d(practical)} = pulse \times f_p + u_k \quad (6)$$

where μ_k is the uncertainties value covering the effects of controller errors, latency, disturbances, and modeling errors.

To update the location of the patrol robot, the current position of the robot is calculated by:

$$(x_n, y_n) = (x_{n-1} + cos(\theta_n),\ y_{n-1} + sin(\theta_n)) \quad (7)$$

The location of the patrol robot will be update for each of the positioning step the patrol robot reaches next (*d = 5cm).* This position update is with condition that if the robot are moving, then update the location based on the θ_n value for each t_d spent while the patrol robot is moving forward.

There is an initial map/floor plan set for the patrol robot during initialization process, before the patrol robot start navigating. The initial map would change each time there is an obstacle detected by the ultrasonic sensors and the corresponding captured image being processed for obstacles along the patrol robot moving path. Point on the initial route on the map would be erased and re-routed using a path planning algorithm as proposed in the following section.

IV. EXTENDED DIJKSTRA ALGORITHM IN PATH PLANNING

A functional path planning algorithm expanded from the Modified Dijkstra's Algorithm [6] for searching alternate routes for robotic patrol task is presented in this section. The suggested algorithm is presented in details as below:

Step 0: **Predefine Map's data**: The map's data is divided into 4 types, as in a sample shown in Fig. 3: Patrolling point labelled as '2', a set of point-to-point data; Local Route labelled as '1', a set of data that connect the '2' from one point to another point; Safe Zone labelled as ' ' and Barrier labelled as '*' for obstacle, wall or cliff.

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Fig. 3. Sample map.

Step 1: **Image Requisition**: ESP32CAM will capture the image during robot patrolling and pass to the Raspberry Pi to perform image pre-processing by transforming the captured image into grayscale and carry out Gaussian noise filtering [8].

The pre-processed image, $\boldsymbol{A}$ is then pass to the Computer (Step 2) to perform obstacle detection.

Step 2: **Obstacle Detection**: Computer with Python programming will perform Gradient calculation with applying Sobel filter for $\boldsymbol{G_x}$ (image contain the horizontal derivative approximation) and $\boldsymbol{G_y}$ (image contain the vertical derivative approximation):

$$\boldsymbol{G_x} = \begin{vmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{vmatrix} * \boldsymbol{A} \tag{8}$$

$$\boldsymbol{G_y} = \begin{vmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ +1 & +2 & +1 \end{vmatrix} * \boldsymbol{A} \tag{9}$$

where "*" indicates the 2-dimensional signal processing convolution operation. The *x*-coordinate is an increasing in the "right"-direction coordinate of an image, whereby the y-coordinate an increasing in the "down"-direction coordinate of an image. From each point in the images $\boldsymbol{G_x}$ and $\boldsymbol{G_y}$, the resulting gradient approximations can be combined to form a gradient magnitude, $\boldsymbol{G}$ and calculate the gradient direction $\boldsymbol{\theta}$:

$$\boldsymbol{G} = \sqrt{\boldsymbol{G_x^2} + \boldsymbol{G_y^2}} \tag{10}$$

$$\theta = \arctan\left(\frac{G_x}{G_y}\right) \tag{11}$$

Non-maximum suppression and Image edge connection [9] will provide a Canny filtered image. The Canny filtered image is then divided into 4 sections:

Bottom Left Section: cover left side region of the image, range from the robot below 25 cm.

Bottom Right Section: cover right side region of the image, range from the robot below 25 cm.

Upper Left Section: cover left side region of the image, range from the robot above 25 cm.

Upper Right Section: cover right side region of the image, range from the robot above 25 cm.

A sample of Canny filtered image with 4 divided sections is shown in Fig. 4. Object detection cells are used to calculate the pixels' value's mean of each sections. For example, in Fig. 4 sample: Upper Right Section spotted pixels' value mean of 5.36, meaning an obstacle is existing in Upper Right Section; whereas for the three other sections (Upper Left, Bottom Left and Bottom Right), there are zero pixels' value mean and hence no obstacles exist in the three sections.

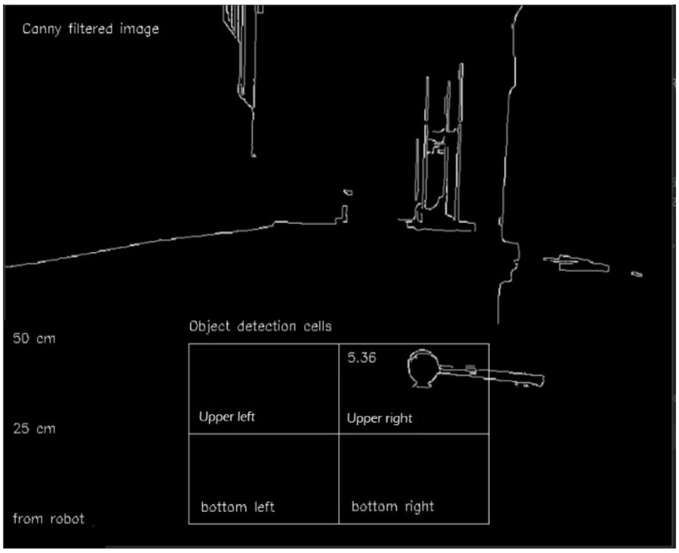

Fig. 4. Sample of Canny filtered image with 4 divided sections.

By total up the pixels' value's mean of each sections, either one of the following three features will be generated:

Feature 1: EITHER Upper Left Section OR Upper Right Section has total pixel value's mean more than 0.

Feature 2: BOTH Upper Left Section AND Upper Right Section have total pixel value's mean more than 0.

Feature 3: NONE of the sections have total pixel value's mean more than 0.

Step 3: **Obstacle Classification:** Obstacle data gathered from Step 2 will be classify according to the difference of intensity by case:

Case 1: **Avoidable Obstacle:** IF the obstacle is blocking the route and avoidable by the patrol robot (Feature 1 triggered), THEN perform obstacle avoidance using at Step 4(i).

Case 2: **Unavoidable Obstacle:** IF the obstacle is blocking the route and not avoidable by the patrol robot (Feature 2 triggered), THEN perform re-route using extended path planning Step 4(ii).

Case 3: **No Obstacle:** IF no obstacle is detected by the patrol robot (Feature 3 triggered), THEN continue move with the planned path. Repeat Step 1 and Step 2.

Step 4: **Extended Path Planning:** Perform the classification and update the local route network.

(i) Based on the obstacle classification, modify the sample map data from Fig. 3 by changing the parameter of Route '1' and Safe zone ' ' into Barrier '*' By using Equation (12), 'r' is approximate range of the obstacle from mobile robot, 'c' is the column the if required and update the map, THEN perform simple neuro-fuzzy control [10] within the Safe Zone ' '. Fig. 5 shown the changes of route from '●' (the begin point) toward '●' (the destine point), in the middle has an obstacle '■' which change the default straight route '●' and moving away toward ' ' (the safe zone).

$$map\ (x_{n+r}, y_{n+c}) = \text{'*'},\ n=0, 1, 2, 3, \ldots \quad (12)$$

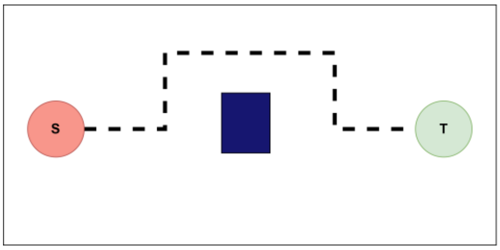

Fig. 5. Obstacle avoidance.

(ii) Based on the obstacle classification, carry out the re-route algorithm:

Dijkstra Algorithm will be adopted to search for the alternative patrolling point arrangement from Patrolling Point '2' data set, during the time searching for the shortest alternative path.

Figure 6 shown a sample of re-Route operation. When the default route from 'S' to 'T' is completely blocked, the patrol robot will seek for alternate path that connected the current position to the 'T' point. The 1st option arrangement is 'S', '1', '2', 'T' but it is blocked at path '2' to 'T', then 2nd option is 'S', '1', '2', '3', '5', 'T', which is the shortest and connected to 'T' point, the 2nd option will then have updated to the map and proceed to Step 5. If the route is blocked again it will keep searching until there is no possible path that connected to the 'T' point, the unreachable 'T' point will be replace with new 'T' point, where the new 'T' point will be the next targeted patrol point.

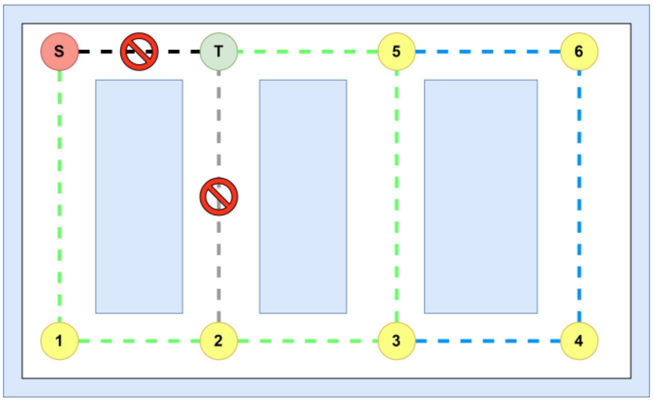

Fig. 6. Re-route sample.

Step 5: **Execution:** The vision based indoor surveillance patrol robot continues to travel pursuant to updated map configuration. Repeat Step 1 and Step 2 till the next obstacle being detected.

V. EXPERIMENTAL RESULTS

The prototype for the vision based indoor surveillance patrol robot is constructed, as shown in Fig. 7. The working prototype was running on a series of experimental tests taken place at second floor of Faculty of Engineering and Technology, Multimedia University (a complex scenario that cover various laboratories, lecturers' offices, test ground, elevator and staircase as a complex scenario) to evaluate the performance of the vision based indoor surveillance patrol robot and the developed path planning techniques. To begin with the experiment, a home position was selected and it is set at one of the edge in the floor plan. The pre-programmed

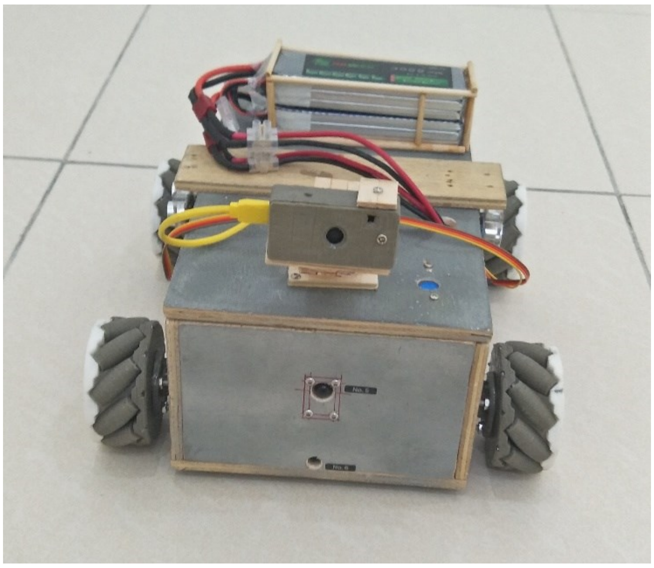

Fig. 7. Vision based indoor surveillance patrol robot.

map and routes in the Computer will then loaded into the patrol robot's raspberry Pi controller before the robot can carry out its patrolling task. The floor map sample showcase the exact environment of the robot patrol path is presented in Fig. 8.

For the performance evaluation, the vision based indoor surveillance patrol robot is performed 250 random movement cycles at the test site. The manipulation elements carried out in this experiment were the opened/closed doors and those random obstacles placed on the tested site. Among the overall 250 tested movement cycles, 225 of the movement cycles were completed successfully (i.e. Patrol robot can travel from home towards destination check point, and return back to the home position accurately), by accuracy of 90%. Those 10% failed robot movement and path planning cases were further analyzed by adopting the fault detection and isolation confusion matrix [11]. The four possible outcomes in the selected experiment test scenarios are specified in Table I.

Substantial emphasizes are placed on True Negative and False Negative cases due to the reason that these two cases may give rise to the uncertainties for the vision based patrol system. Throughout the 25 failure path planning cases, 19 of the cases be associated with True Negative class and 6 of them be associated with the False Negative class. Probed deep into these 16 True Negative cases and 9 False Negative cases, being observed that in True Negative cases, the obstacles along the travelling path were detected and been classified accurately. Anyhow, error data capturing from Inertia Measurement Unit (IMU) unit guiding to the faulty path planning. Meanwhile, it is observed that in False Negative cases, the obstacles' color that close to the floor and walls' color were not identified as obstacles, rendering the patrol robot to bump toward/strike the obstacles and get stuck, causing the failure of IMU unit to update the robot location. The above two Negative result cases failed the vision based indoor surveillance patrol robot's home returning function. The prompt mitigation plan is by adding ultrasonic sensors at the front and sideway of the vision based indoor surveillance patrol robot to operate as a precautious measurement to identify the obstacle with color and pattern similar to the surrounding floor/wall.

Table II presented the elements and sources that affecting the accuracy and uncertainty of the vision based indoor surveillance patrol robot, extracted from the above 250 trial movements' experimental results. The four elements that affected the performance of the vision based indoor surveillance patrol robot included obstacle detection, obstacle classification, odometry and path planning.

Table I. Confusion Matrix Definition.

True Positive (206)	• The obstacle is detected, classification is correct, path planning is correct, IMU system without error, patrol robot able to reach home position.
True Negative (19)	• The obstacle is detected, classification is correct, path planning is correct, IMU system with error, patrol robot not able to reach home position. • The obstacle detected, classification is correct, path planning has faulty, IMU system with error, patrol robot not able to reach home position
False Positive (19)	• The obstacle is detected, classification is false, path planning is correct, IMU system without error, patrol robot able to reach home position. • The obstacle is not detected, obstacle is negligible, path planning is correct, IMU system without error, patrol robot able to reach home position.
False Negative (6)	• The obstacle is not detected, obstacle is not negligible, path planning has faulty, IMU system with error, patrol robot not able to reach home position.

Table II. Elements and Sources That Affecting the Patrol Robot.

Element	Source	Accuracy	Uncertainty
obstacle detection	• robot vision • ultrasonic sensor	0.94	0.06
obstacle classification	• obstacle detection	0.93	0.07
odometry	• gyroscope • accelerometer	0.95	0.05
path planning	• obstacle detection • obstacle classification • odometry	0.91	0.09

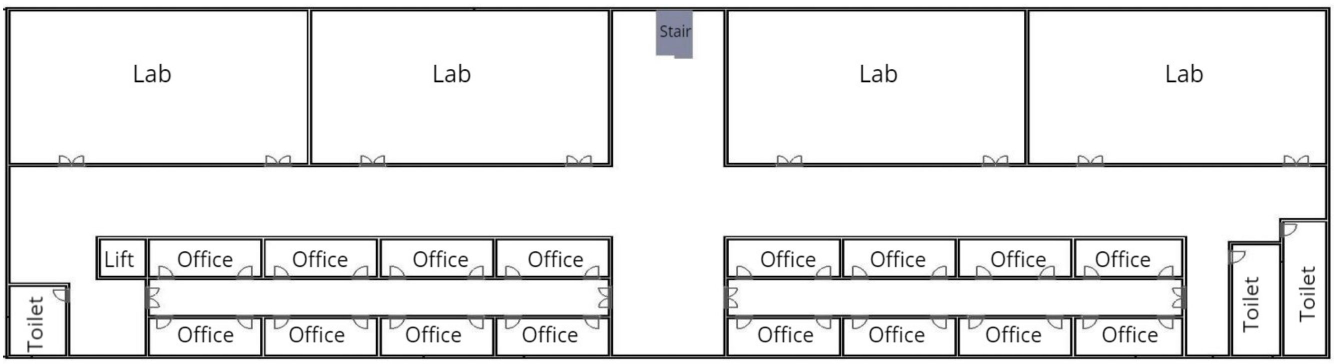

Fig. 8. Sample floor map of the test site.

The accuracy and uncertainty of the vision based indoor surveillance patrol robot's patrolling loop is calculated based on the success/faulty occurred in the conducted experimental trials. The obstacle detection depends on the robot vision and ultrasonic sensor to make successful patrolling loops. This element committed 6 % of the failures. Such failures induced by the sensor/ imaging tool's refresh rate that focus on an area to take shot, while the patrol robot is moving, and hence blur info is being taken. The obstacle classification further depends on the obstacle detection to make successful patrolling loops. This element contributes 7 % of failures. Such failures not only induced by the blur info of the robot vision and ultrasonic sensor, it also induced by the misclassified of obstacles that has the same colors with the background (floor and walls). The odometry depends on the patrol robot's accelerometer and gyroscope to make successful patrolling loops. This element contributes 5 % of failures. Such failures induced by the odometry data accuracy, particularly on the systematic and random errors [11]. The path planning element is relying on the three elements stated above (obstacle detection, obstacle classification and odometry) to make successful patrolling loops. Therefore, all the failures above are accumulated, with some overlapping outcomes, shares up to 9 % of total failures to the patrolling loop movement.

Thus, concerning to enhance the path planning element, the below concerns need to be settled:

1) Ultrasonic sensors' refresh rate ought to be well tuned.
2) Imaging tool shall capture image only when the patrol robot is stop moving. Else, blur effect cancellation method shall be figured out for the image capturing process.
3) Ultrasonic sensor shall be work synchronously with the imaging tool, mutually identified obstacles in the path planning process.
4) The odometry's data error correction method shall be figured out to handle the systematic and random odometry errors.

After the concerns stated above resolved, the vision based indoor surveillance patrol robot platform shall be well supporting the extended Dijkstra algorithm in the robotic path planning for robot patrolling or in any other robot routing tasks.

VI. Conclusion

This paper introduced a vision based indoor surveillance patrol robot and an extended Dijkstra algorithm for the patrol robot path planning. The fabricated vision based indoor surveillance patrol robot prototype had been tested with the proposed patrol robot path planning algorithm and attained the intended path planning target for a patrol robot with accuracy as higher as 90 %. Confusion matrix had been adopted to analyze the failures' root cause and a few of the enhancement steps had been proposed. The on-going Canny Edge obstacle detection and classification method is having the constraint of misclassified obstacle that are having color/pattern that are identical to the floor/wall. In the future, Artificial Intelligence and machine learning will be adopted to restore the present proposed Canny Edge obstacle detection method in obstacle detection and classification. Meanwhile, the incorporation of the robot vision sensing elements such as LiDAR, depth camera and 360-degree camera shall be able to provide more environmental information on the patrolling scene in the augmented reality form for path planning. All of this will be addressed in future work.

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