Underneath Vehicle Inspection Using Fuzzy Logic, Subsumption and OpenCV Library

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Abstract**—**The inspection of underneath vehicle system has been given significant attention by governments after the threat of terrorism become more prevalent. New technologies such as mobile robots and computer vision are led to have more secure environment. This paper proposed that a mobile robot like Aria robot can be used to search and inspect the bombs under parking a lot vehicle. This robot is using fuzzy logic and subsumption algorithms to control the robot that movies underneath the vehicle. An OpenCV library and laser Hokuyo are added to Aria robot to complete the experiment for under vehicle inspection. This experiment was conducted at the indoor environment to demonstrate the efficiency of our methods to search objects and control the robot movements under vehicle. We got excellent results not only by controlling the robot movement but also inspecting object by the robot camera at same time. This success allowed us to know the requirement to construct a new cost effective robot with more functionality**.**

Keywords**—**Fuzzy logic, Mobile robots, OpenCV, Subsumption, Under vehicle inspection.

I. Introduction

VEHICLE inspection is become more interesting subject around world especially in the recent years a number of car bombers are increased significantly. Many organizations and governments were interested to design different systems to inspect different place of vehicle for security reasons. Among the places that must be inspected are vehicle's underneath. One of the common methods used in checkpoint inspections to inspect vehicles underneath is the convex mirror method. But, this method has several weaknesses, such as it does not cover the whole area underneath vehicle, for example the areas close to a vehicle's wheels, the lightning conditions under a vehicle can be affect visibility and the view angle is restricted when using physical mirror types [1], [2].

Furthermore, this mirror cannot reach the middle places under a car and finally it is not safe for the operator of the mirror in case the vehicle has real explosive materials attached to it. These might probably explode during the vehicle inspection.

Conversely, there is another method called "phony bomb detector" which is even worse than common mirror inspection. The user of the device was given a variety of programmed cards to inspect different substances; however these cards contained no technology at all. This device failed in many occasions to inspect vehicles in many countries including Iraq [3], for more details see Fig. 1.

Fig. 1 The 'bomb detection' device is supposedly powered by static electricity [3]

A. Overview

The goal of this project is to construct an under vehicle inspection system. We used a mobile robot like Aria robot for under vehicle inspection because Aria robot enable us to have a complete under vehicle inspection such us necessary sensors required navigating in the environment without requiring significant construction. We used a new way which is fuzzy logic and subsumption algorithm to control the robot navigation underneath vehicle. After this experiment is succeeded then we can easy build our robots with less cost and more functionality.

This experiment is designed to inspect a vehicle which is parking a lot in road side and enable the robot to search under vehicle by going forward and return backward while presenting a real time video by using robot's camera. By using the robot camera and OpenCV library the operator can see objects under vehicle while the robot navigates under vehicle.

The basic design and operation of our experiment are using the OpenCV library (to enable the robot camera to take photos or videos in real time) and attach second laser Hokuyo to the Aria robot which is facing upside to keep the robot go forward and backward by using fuzzy logic algorithm. As the vehicle is stationary the robot start moving under vehicle while avoid the vehicle's wheel by using subsumption algorithm. The camera takes simultaneous recording while the angle of view and resolution is controlled by special programmed class.

B. Current Commercial System for under Vehicle Inspection

Clearly, the convex mirror inspection is the most common method was used for under vehicle inspection [4] . Some of convex mirror have become more advanced and permit the inspector to accomplish the same search with a camera [4]. There are other alternative ways proposed by some investigators like employing arrays of cameras, installing on inspection bay on ground. This method is able to detect the

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material attached to a vehicle when the vehicle moves over the arrays of cameras [4].

However, this method demonstrates the slow movement of the car over the arrays of the cameras; it also requires the correct direction of vehicle movement when a vehicle is moving over these cameras. Furthermore, this type of system is designed to be in fixed sizes, hence, when the model or size of vehicle is changed, the vision might be completely lost in some areas under the vehicle during vehicle movement above the cameras.

C .Previous Achievement at under Vehicle Inspection

As we mentioned in section 1.2 about the under vehicle inspection, there is also a modern way which is fake car bomb detector which was managed by the director of ATSC "Jim McCormick" who was arrested by the UK government because his company sold the fake bomb detectors to several countries including Iraq [3]. ATSC claims that the car bomb detector could detect and find very small quantities of explosives which might lie one kilometre away, but this claimed was completely not real [3].

All previous methods assume the vehicle are moving in queue and the operator able to decide either to pass or block some vehicle to be in the second stage of inspection. However, when the vehicle is parked for a long time on a street or near a governmental building, these methods are either too risky to implement or they completely do not work.

Recently, it has been experiment by[5] using a mobile robot with a LRF Sensor, but this method depend on acquire data or image from the previous scan and compare with the next scan to make difference between them to detect the suspicious object which may attach underneath vehicle. However, this method require a level of complexity such as construct design, processing data and it was not robust when the terrorist try hid the explosive material with the same colour of under vehicle colour. Furthermore, their ways did not include obstacle avoidance during robot navigation underneath vehicle.

This experiments is the first method using fuzzy logic algorithm to search under vehicle by keeping the mobile robot go forward and return backward while the robot camera acquire real time video for the object underneath vehicles. In this experiment, the fuzzy logic is controlled the distance between underneath vehicle and the top of the robot body while the subsumption algorithm used to avoid the wheel of vehicle when the mobile robot navigates under vehicle.

It is worth mentioning that our experiments took place at the indoor experiment. Furthermore, in order to simulate the area underneath a potentially suspicious vehicle, woods, boxes of woods and tables were used for this purpose.

Finally, a summary of under vehicle system architecture, the estimation of movement planning by fuzzy logic with subsumption algorithm and the computer vision by using OpenCV regarding robot camera are presented at Section II. Hardware requirement for building a new mobile robot is presented at Section III. In Section IV, we provided the experimental results for testing our ways for under vehicle inspection. Finally, the conclusion and future work are presented at Section V.

II. Under Vehicle Inspection System

Our aims are to create a system for under vehicle inspection of a vehicle which is stationary at road side. We must check under vehicle for contraband or bombs attached by using mobile robot which is in our experiment the Aria robot.

Three sensors were used for under vehicle robot navigation and bombs detection. Aria has originally two sensors, one is laser range finder Sick LMS-200 at the front of robot body and the other one is Canon camera VCC on the top the robot body. We added one sensor which is Hokuyo URG-LX04 laser range finder facing upside of robot body.

The front laser range finder "Sick" responsible for calculating the distance to obstacle like under vehicle wheels or the prospect obstacle at the middle of the vehicle. The second laser range finder "Hokuyo" responsible for calculating the distance between the robot body and under vehicle, furthermore it is also responsible for sensing the edge of vehicle when the robot reaches the end of under vehicle. Finally the robot's camera feed the operator about objects which may lie under vehicle by using OpenCV source codes.

A. Movement Planning at under Vehicle Inspection

We have to make the robot go forward and return backwards to inspect the area underneath of the vehicle. Therefore, we are going to use software to control the robot movement and we also need to use some of the robot’s control algorithms. One of these algorithms is the fuzzy logic algorithm.

When a mobile robot start moving underneath vehicle the second laser start to collect date, these date are translated by fuzzy logic controller. The fuzzy logic try to keep the robot return back underneath vehicle when the robot reaches the edge of the car to search other areas that is not covered in the first scan, more details see Fig. 2.

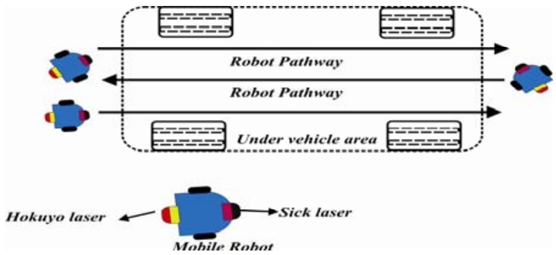

Fig. 2 Robot motion under vehicle area

The reason of using fuzzy logic control is that fuzzy logic is better solution to deal with uncertainty [6]-[9]. Furthermore, when the robot reaches the edge of the car, the fuzzy provides information to the robot that the robot is slightly approaching the outside of the car. Hence, the robot takes the required action to modify its movement and return underneath vehicle.

For the fuzzy logic algorithm, we were used three input membership function zones {Inrange, Midrange, Outrange}. For fuzzy input zones in number, the Inrange zone (from 0cm

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to 60cm) represents the distance between under vehicle area and the robot body which inform robot to slow movement during navigation, however the Midrange zone (from 60cm to 100cm) represents that the half of robot body underneath vehicle and the second half is outside underneath vehicle. Finally the Outrange zone (from 80cm to 5000cm or more) represents that the robot is outside from the under vehicle, while the x-axis represent the membership function range between 0 and 1. For more details see Fig. 3.

Fig. 3 Input membership functions for laser reading sensors

These zones are represented the three input data acquire from second laser and three output zones for robot motor speeds {Slow, Medium, Fast}. We represented the singleton membership for the three output membership functions, for slow speed is 50RPM, Medium is 250RPM and Fast is 350RPM, more details can be seen in Fig. 4. These speed applied to the robot wheel when the robot navigate under vehicle.

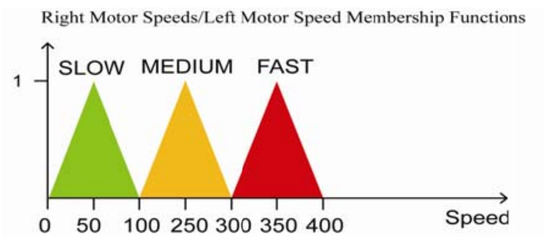

Fig. 4 Output membership function for the robot wheels

We used high defuzzification way for the fuzzy logic inference rules along with nine rule bases see Table I.

TABLE I
THE NINE RULE BASES OF FUZZY LOGIC REQUIRED CONTROLLING THE ROBOT

Ser	Input from sensors to the fuzzy zones			Output motor speeds	
	Left sensors	Middle sensors	Right sensors	Left motor	Right Motor
Rule I	Inrange	Inrange	Inrange	**Slow**	**Slow**
Rule II	Inrange	Midrange	Midrange	**Slow**	**Med**[1]
Rule III	Inrange	Outrange	Outrange	**Slow**	**Fast**
Rule IV	Midrange	Inrange	Inrange	**Med**	**Slow**
Rule V	Midrange	Midrange	Midrange	**Med**	**Slow**
Rule VI	Midrange	Outrange	Outrange	**Slow**	**Fast**
Rule VII	Outrange	Inrange	Inrange	**Med**	**Slow**
Rule VIII	Outrange	Midrange	Midrange	**Fast**	**Slow**
Rule IX	Outrange	Outrange	Outrange	**Slow**	**Slow**

1- Med: Refer to Medium speed

B. Avoid Wheel of a Vehicle during Under Vehicle Scanning

We also have to avoid an obstacle during the robot navigation under the vehicle or when the robot becomes close to the wheel of the under vehicle. Therefore, we have to combine two behaviours of robots by using a *subsumption* algorithm: one behaviour to keep robot underneath the vehicle which is done by using fuzzy logic and the other behaviour to avoid wheel of the vehicle during robot navigation. Hence, we have to employ some of the front sensors of Aria's robot like another laser range finder " Sick" to avoid wheel of underneath vehicle or obstacle which may lie under vehicle. The path way of mobile robot was explained in Fig. 2, furthermore, the new path way of mobile robot by using subsumption is showing in Fig. 5: the red line colours show the paths are considered to avoid obstacle (wheel of under vehicle) when the robot complete first scanning by fuzzy logic and comes close to vehicle's wheel.

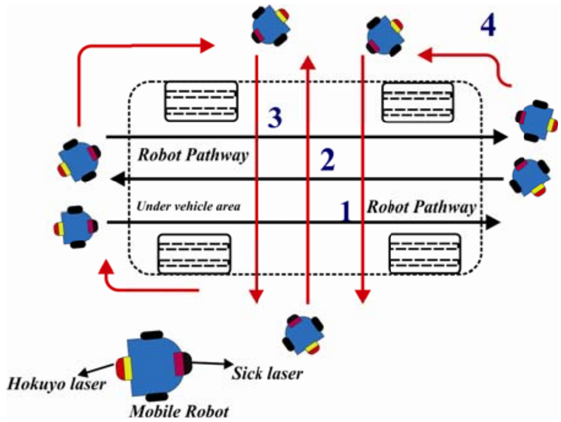

Fig. 5 Avoid vehicle's wheel during the robot navigation

In Section *A*, the robot keeps navigating underneath vehicle and searches the most areas underneath vehicle except the areas which are close to vehicle wheel. However, the robot now was able to scan the whole area under vehicle without any problem along with the dynamic obstacle which may place at the middle of vehicle.

In fact, using subsumption algorithm provide us a good way of robot localization because the robot can correct its movement when comes close to under vehicle wheel, making the robot continue to search under vehicle area either in horizontal or vertical depending on the first direction of the robot movement in the environment.

C. Overseeing Under Vehicle Objects

We accomplished a method that makes the robot staying underneath the vehicle; we need to recognise the objects underneath the vehicle, like the bomb that is attached to the body of the vehicle. Hence, we must employ a way enable us to see objects under vehicle. However, employing a camera to see an object requires the use of software to program the robot's camera. The more suitable software or source code and easy to code is OpenCV software library. OpenCV software library provides the necessary function for the robot camera to operate the camera in real time to inspect underneath the vehicle. We programmed the OpenCV code which enables us to have a window that provide us the picture of under vehicle and record a video when necessary. We developed OpenCV with some commands which enable us to control the pan-title and zoom of camera so that we can move the position of camera during robot navigation under vehicle, furthermore, we can zoom-in, zoom-out and move the camera in 240 degrees. Hence, an OpenCV help us to identify the suspicious object which may lie under vehicle by using only a robot camera with some commands.

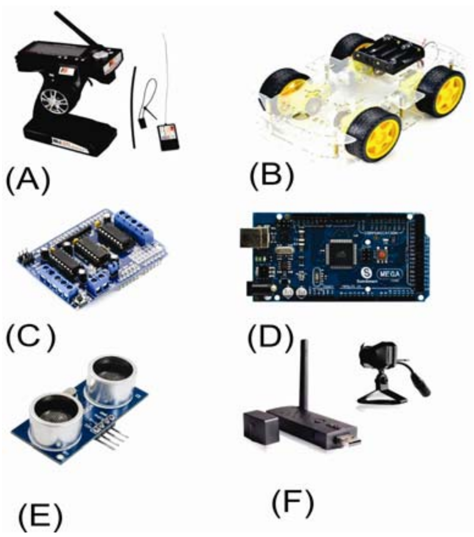

Fig. 6 Hardware requirement for building mobile robot under vehicle inspection

III. Hardware Implementation

For implementing our experiment on a new robot we need to build a robot that have the following:

1. Flysky FS-GT3B 3CH 2.4GHz Transmitter + Receiver for RC Car. This RC required controlling the robot and sending it underneath the vehicle by employing radio communication (see Fig. 6 A), then the autonomous behaviour will be take a role for under vehicle inspection.
2. Four-wheels Robot Smart Car Chassis Kits Car with Speed Encoder for Arduino. This chassis will be employ to attach the required board, which is necessary to drive and control the robot (see Fig. 6 B).
3. eFuture (TM) L293D Motor Drive Shield Expansion Board Fit For Arduino Duemilanove Mega UNO R3 AVR ATMEL + e Future's nice Keyring. This board is employed for controlling the speed of the DC motor or the servo to give more torque to the movement of the robot during navigation (see Fig. 6 C).
4. Ultrasonic Module HC-SR04 Distance Sensor for Arduino. This sonar sensor will be employ to estimate the distance from the vehicle to the robot. It will also use to either avoid obstacles or keep the robot staying underneath vehicle. (See Fig. 6 E).
5. Sain Smart MEGA 2560 Board for Arduino. This microcontroller was employed to control the robot movement and behaviour and it can be controlled by programming the board Arduino by either C or C++ language (see Fig. 6 D).
6. Four Ch 2.4G Colour Mini Wireless Security Camera Real-time PC Based USB DVR Kit. This wireless camera is employed to transfer the images that are taken under the vehicle (see Fig. 6 F).

As a result, our project cost will be $ 200 which is much cheaper than the fake car bomb detectors, all the estimating prices are from Amazon web site.

IV. Experimental Results

We started to test a mobile robot in our labby simulating car with dimensions of (5 meters length and 2 meters width). When the robot start moving, the two laser range finders start acquiring data from environment and pass the data to the microcontroller inside the mobile robot. The robot starts seeking for under vehicle areas. As soon as the mobile robot became in the range of under vehicle, it started to go forward and return backward because the fuzzy logic algorithm translates the data from Hokuyo laser to control the robot motion under vehicle (see Fig. 5 the black lines).The velocity of the mobile robot is different from one situation to another, depending on the input from robot's sensor. As soon as the entire robot body became underneath vehicle, it starts to slow speed according to base rules (more details see Rule 1 in Table I) The robot continued to search under vehicle base on the paths (1 to 3) until it reaches the one wheel of under vehicle then the mobile robot take the 4 path (see Fig. 5 the red line). For paths (1 to 3) the robot cover the entire areas except the areas which is close to under vehicle wheels, however the path 4 is change the direction of robot movement, making the robot to cover the areas close to the robot wheels. At this point the robot covers the entire area of under vehicle while the robot camera feeds the operator the video and picture of the object which may attached underneath vehicle.

For the first searching of a mobile robot(path 1) and when the mobile robot comes under vehicle the data were gather from Hokuyo laser range finder were as follows, from the left side of the mobile robot was 30.3cm, at the middle side was 11.1cm, and the right side was 25.5cm, these reading date are translated by fuzzy logic algorithm, resulting the Rule 1 to be fired (more details see Table I) and the robot had to slow speeds, (more details see Table II). Then the mobile robot took 30 seconds to finish the path 1 to reach the other side of vehicle. Now, the robot rotates at degree 45 degrees to follow the path 2.At this point the reading data from Hokuyo laser finder were 30.3cm at the left side of robot, 80cm at the middle side, and 78.8cm at the right side making the Rule 2 to be fired (see Table II), Rule 2 has to make the robot rotates left, hence the speed of left motor is 50RPM and right motor 250RPM.

When the robot reached other side for the third times, the reading data from sensors were 73.9cm at the left side of the robot, 40.6cm at the middle side and 35.2cm at the right side, making the Rule 4 to be fired (more details see Table I and II) while the speed of the left motor was 178RPM and the right motor was50RPM, making the robot to turn right to complete path 3. After90 seconds from navigating under the vehicle the robot reaches the other end of the car but at this time the robot covered the entire area of under vehicle. Afterwards, the robot started to rotate to the right side because Rule 2 or Rule 3 fired (see Tables I and II). At this point the robot face an obstacle which was the vehicle wheel, hence the subsumption algorithm starts working. The robot started to avoid obstacles and came under vehicle again (see Fig. 5 the red lines). The complete searching and navigation under vehicle were approximately 2 minutes including avoid the obstacles.

TABLE II
DATA FROM SENSORS AND FIRED RULES OF FUZZY LOGIC

Data from Hokuyo "UP Laser"			Output to Robot wheels		**Rule fired**
Left sensors	Middle sensors	Right sensors	Left Motor Speeds	Right Motor Speeds	
30.3cm	11.1cm	25.5cm	50RPM	50RPM	RuleI
30.3cm	80cm	78.8cm	50RPM	250RPM	RuleII
52.1cm	124cm	135cm	50RPM	350RPM	RuleIII
73.9cm	40.6cm	35.2cm	178RPM	50RPM	RuleIV
78.8cm	127cm	130cm	50RPM	350RPM	RuleVI
81.2cm	80cm	78.8cm	250RPM	50RPM	RuleV
132cm	60.3cm	32.7cm	250RPM	50RPM	RuleVII

After the first success result on potentially vehicle (5 meters* 2 meters) we tried to test our results on a different size of vehicles. We found our experiment results succeed on the different dimensions such as 4 * 2 meters, 5 * 3 meters, and 3 * 2 meters. All previous tests provide us successful results that were making the robot motion and inspection working invery good performance. Furthermore, we developed the under vehicle systems by using sixteen rule base which also provide us successful results.

Finally, the OpenCV roles provide us the photos taking from robot camera to the operator to see the object which may attach to under vehicle, the sample took from robot camera using OpenCV can be seen in Figs. 7-9)

Fig. 7 Test mobile robot vision at under vehicle inspection (Dimension 4*2 meters)

Fig. 8 Test mobile robot vision at under vehicle inspection (Dimension 4*2 meters)

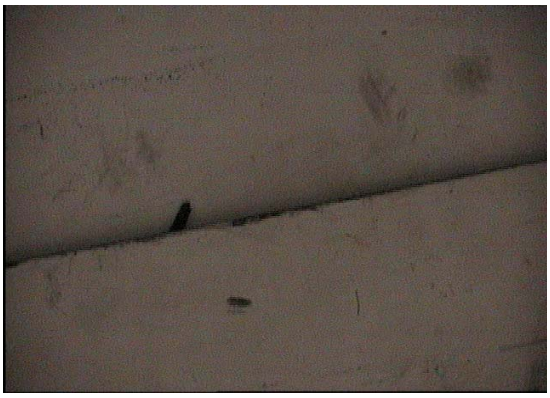

Fig. 9 Test the mobile robot vision at under vehicle inspection (Dimension 4*2 meters)

V. CONCLUSION AND FUTURE WORK

Vehicle bomb attacks and illegal immigration have obliged governments to pay more attention to under vehicle inspections. The traditional methods such as mirror inspections, fake bomb detectors and fixed under vehicle camera inspections, have significant weaknesses when facing vehicle bomb attackers. Mobile robots and computer vision play an important role to fight the vehicle bomb attacks.

Fuzzy logic and subsumption algorithms try to keep mobile robot under the vehicle and moving forwards and backwards. Using these algorithms are better choice for several reasons such as it deals with uncertainty very well, this means the robot is able to sense the edge of the under vehicle and it provides a smooth transition in the robot movements during navigation.

Using subsumption algorithm helps us to consider the four wheel of vehicle as beacons, making the robot to complete searching at the horizontal direction after completing the vertical direction or vice versa (when the robot start scan from width of vehicle rather than at vertical direction).

Regarding the robot's camera control, we improved our under vehicle inspection system by zooming in and out, changing the direction of the camera and recording video from the robot camera. All of these features were combined with

OpenCV library and therefore we got more flexibility to control at the robot camera.

This experiment was conducted on an Aria pioneer robot to check the efficiency of our methods and algorithms; hence we can easy create a new mobile robot with less cost and more software functionality.

As future works, we can support the mobile robot with an advance camera like Infrared camera so the robot able to inspect easily during night time or we can supply the robot by extra light or bulbs to work during night. For building a new robot we can used IR sensors instead of laser range finder (because high prices) and it is more accurate than sonar sensors.

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