Prototype for Localization of Multiple Fire Detecting Mobile Robots in a Dynamic Environment

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Abstract – Cataclysmic circumstances around the globe are increasing day by day either because of some severe natural disasters or human faults. Fire occurrences have a place with the latter kind of fiasco, which typically need to do with human mistake. The biggest casualties of fire risk are generally the commercial ventures, processing plants, oil refineries, industries and comparative locales, which essentially work with combustible or volatile materials. Surveillance of such sites is the requirement to build security for the human work power and property. This work displays a model for the observation of an imitated fire site utilizing multiple fire identifying robots. This model addresses localization of two fire detecting mobile robots on a round lattice in a dynamic domain. The robots are assembled with the LEGO MINDSTORMS NXT 2.0 kits and are customized via LabVIEW Module of LEGO MINDSTORMS (LVLM). The aforementioned mobile robots – revolving in circular movement – screen the imitated fire site and when any of the two robots identify a flame, they perform certain characterized tasks. The Bluetooth protocol feature is used to establish communication between the two robots. Each robot is equipped with a thermal infrared sensor (TIR) by Dexter Industries for detecting fire and an ultrasonic sensor to avoid collision with obstacles being presented with a dynamic environment.
Keywords – LEGO MINDSTORMS NXT, LabVIEW, LVLM, TIR.

NOMENCLATURE

GPS: Global Positioning System
LVLM: LabVIEW Module of LEGO MINDSTORMS
TIR: Thermal Infrared Sensor
VI: Virtual Instrument

I. INTRODUCTION

Fire incidents are to a great extent reported to be the reason behind successive catastrophes everywhere throughout the world. The severe outcomes of such and various incidents are normally distinguished as the late acknowledgment of the fire site and the time taken for the fire extinguishing work power to achieve the influenced site. Additionally, a critical truth is that the most usual casualties of fire incidents are typically the industrial sites as referred in a report carried out by Aristotle University, Thessaloniki, Greece in 2012 [1]. Different efforts to establish safety have been considered and furthermore the firefighting capacities enhanced all around the globe, yet directing fire fighters into horrible flames is likewise rising the death proportion. To address this, firefighting robots have been produced to reduce fatalities because of fire incidents.

Several efforts have been made to employ robots in the capacity of fire extinguisher, a remote fire alarm, or both [2] [3] [4]. Effective monitoring, high speed recognition and extinguishing of a fire are still requirements to immediately deal with fire incidents at industries involved in the business of working with combustible materials, for example, regular gas, petroleum or relative chemicals. So as to prevent such business sites from being influenced by extreme fire hazard, the notion of monitoring the most susceptible zones of a plant may be established using multiple mobile robots within a range and the nearest robot can carry out the task of moving towards the flame and extinguishing it.

The available literature demonstrates a range of methods to develop the fire extinguishing and firefighting robots for diverse circumstances and for different type of sites, along with enhancing/upgrading the systems from time to time. In [4], authors proposed a fire sprinkler design built by utilizing LEGO NXT MINDSTORMS Kit, equipped with an infrared camera for image acquisition and a dispenser solenoid for releasing a fire quenching agent. This investigation demonstrated localization of one robot and presented an efficient model for fire hazard protection in homes and buildings. A multi-robot approach could add to the features of the safety measures offered by the above mentioned study if the application, such as industrial sites, is more sensitive.

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In another published work, authors described a robot which searches for toxic gases and high temperatures in serious conditions due to a fire incident and it conveys information regarding the severity of fire site along with information concerning any victims to its remote unit [5]. An autonomous firefighting mobile platform assembled using a fire quenching system, motor driving capability, flame sensors, LDR (Light Dependent Resistor) sensors, ultrasonic sensors and LEDs (Light Emitting Diodes) is discussed in [6]. However, concept of line following was employed for localization in a prescribed area for surveillance and a number of different sensors make the framework complex. A firefighting robot is demonstrated in [7] with a computer vision methodology for navigation control and fire recognition using video acquisition feature of MATLAB (Matrix Laboratory). Although, no obstacle avoidance feature and misidentification of flame owing to the intensity of encompassing light and changed threshold of colour segmentation in different settings adds to the shortcomings of this methodology.

The proposed prototype here for localization of multiple fire detecting mobile robots utilizes limited resources, such as cost and number of sensors, to accomplish the task of locating the fire and reaching at the fire site in a dynamic environment. Each robot in this research project utilizes the LEGO MINDSTORMS NXT 2.0 kit and two motors (available in the kit), and only two sensors - an ultrasonic sensor (available in the kit) and a thermal infrared sensor (purchased separately). The LabVIEW module of LEGO MINDSTORMS (LVLM) is utilized for programming the robots. Further sections in the paper will discuss about the objective and essential requirements of the project, the proposed methodology, programming flow charts and graphical representation of the algorithm, results and discussion, conclusion and future scope of the work.

II. OBJECTIVE AND ESSENTIALS

The main objective of this work was to outline a model for the localization of multiple fire identifying mobile robots in a dynamic space. The principle goals of this model are described as follows:

1. Fire identification.
2. Robot localization.

These tasks are broadly discussed in the Proposed Methodology Section, but the fire extinguishing task is not covered in this prototype since the containers for fire quenching agents would be too bulky to be housed within this model. However, a manipulator with the suitable capacities of quenching a fire can be intended to execute the fire extinguishing work in a practically real-world model. Hardware and software descriptions constitute the essentials for accomplishing the above objectives and are given in the sub sections below.

A. LEGO Mindstorms NXT 2.0 Kit and Sensors

Set of equipment in the LEGO MINDSTORMS unit is widely used as a means of education, research and hobby. Engineering scholars make use of these kits for science and technology tasks and for research on numerous real-world problems [8] [9]. Two LEGO NXT 2.0 MINDSTORM units are utilized as a part of this work to design the proposed fire identifying robots, which were constructed using following identical hardware:

1. NXT Brick: It is essentially a computer in brick shape, works as the intelligent processing unit of the NXT Mindstorms NXT 2.0 Kit. It incorporates a 32-bit Atmel AT91SAM7S256 microcontroller with the capacity of four input ports for receiving data from sensors and three output ports for directing maximum three motors.
2. Thermal Infrared Sensor (TIR): In comparison to the color or light sensors used for fire identification, thermal infrared sensor (TIR) is an optimal choice to detect fire immediately because of its temperature driven functionality. Two TIR sensors were purchased by Dexter Industries at the cost of $54.9 each, having capability of temperature sensing between -70°C and +380°C (-90°F and 700°F) in the range of 2 meters distance [10].
3. Ultrasonic Sensor: It works as “eyes” for the robot and helps in performing obstacle detection. This sensor is available in the LEGO NXT kit and has the functionality of determining an obstacle’s proximity in centimetres or inches.
4. Motors: The LEGO MINDSTORMS NXT 2.0 pack accompanies three servo motors for controlling the motion of robot according to the specific application. Each servo motor has a built-in rotation sensor which helps in accumulating the distance and speed a robot has covered in terms of rotations.

Construction of both robots followed the same steps presenting a 4 wheel vehicle outlook. Fig.1 shows the front outlook of a fire identifying robot, clearly equipped with two aforementioned sensors.

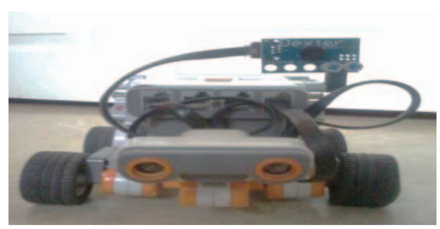

Fig.1. Front outlook of a fire identifying robot

B. NI LabVIEW Module for LEGO MINDSTORMS (LVLM)

LabVIEW toolkit for LEGO MINDSTORMS introduced by National Instruments features highly flexible environment for programming the educational robotic kit, highlighting the implementation of science & technology applications. LVLM toolbox offers a user-friendly way of learning to control the LEGO MINDSTORMS by creating Virtual Instruments (VIs) and in comparison to the standard software (NXT-G) accompanied with the LEGO kit, it provides with more number of functions.

III. PROPOSED METHODOLOGY

The proposed methodology includes following main parts and they cover the design of the emulated fire site, the localization technique and implementation algorithm.

A. Emulated Fire Site

A fire site is emulated utilizing a round lattice/grid having 4 inch sized cells, keeping in mind the separation between front and back steering wheels of the designed robot as it may help in verifying the location of robot according to calculations. The circular lattice is graphed to have a diameter of two meters in order to agree to the scope of the TIR sensor to recognize the fire in defined range. So as to avoid a dead zone in fire detection by TIR sensor, the grid was preferred to be in a circular shape. Candles were used as an example source of fire.

B. Localization Technique

Localization demonstrates the location of a robot in any environment, be it is indoor or outdoor. Localization methods may not deliver same results for the differently organized robots employed in different settings [11]. Compass sensors or Global positioning system (GPS) are generally utilized to perform localization task, however many other techniques are also used for accumulating the position of a robot. Other techniques include rotation sensors, IR sensors and sonar, and these techniques provide more optimal results in indoor environments as compared to GPS [12].

This project uses simple odometry equations to evaluate the location of the robot using the number of rotations (in degrees) provided by the built-in rotation sensors in the motors of LEGO NXT MINDSTORM kit. Rotational data (degrees) are converted into inches or centimetres by making use of the circumference of robots' wheels and this way each wheel's covered distance is calculated. The particular position in the grid where the robots are performing fire monitoring by moving around in circular motion is considered to be their initial position before fire detection i.e. $(x, y) = (0, 0)$. As soon as a robot begins moving towards flame on instance of fire detection, its position is updated utilizing the information extracted by the built-in encoders. Then the change in orientation $\Delta\theta$ and distance Δs covered by the robot is accumulated using the distance information of right and left wheels, Δsr and Δsl respectively and the separation between the two wheels along the dimension of the axle from centre to centre of the wheels, b. Simple odometry computations are used to determine these parameters [12, 13]. Eq. 1 and Eq. 2 demonstrate Δs and $\Delta\theta$ equivalences respectively.

$$\Delta s = \frac{\Delta s_r + \Delta s_l}{2} \qquad (1)$$

$$\Delta\theta = \frac{\Delta s_r - \Delta s_l}{b} \qquad (2)$$

Accordingly, with the use of trigonometric computations change in x-coordinate, x' and change in y-coordinate, y' are evaluated and the new updated position of the robot i.e. x_{new} and y_{new} co-ordinates is determined as shown in Eq. 3 and Eq. 4.

$$x_{new} = x + x' \qquad (3)$$

$$y_{new} = y + y' \qquad (4)$$

This information is utilized to determine that how far the robot has travelled from its initial point after sensing a flame. Consequently, this updated co-ordinate/position data is utilized for the robot to return towards its initial location after reaching a fire.

C. Implementation Algorithm

The implementation algorithm is sub-divided into four tasks:

1. Fire identification.
2. Bluetooth communication between robots.
3. Localization and obstacle detection.
4. Returning back to the initial position.

1. Fire Identification

Each robot is programmed to perform the surveillance of the imitated site all the time in a circular motion so as to screen the complete area and each of them is set to a random position in the lattice, considering that position or (x, y) co-ordinate to be their reference or initial point. During this rotatory motion, each robot does the job of fire detection constantly and the TIR sensor is already defined to sense the object temperature instead of ambient temperature in order to easily detect the accurate location of flame. Robots will continue to rotate around their reference point until object temperature at any particular direction exceeds the room temperature (i.e. a fixed point which may be customized while programming according to the changing environment), for instance 32°C. As soon as any or both of the robots identify that exceed in temperature set point, they will communicate with each other through Bluetooth to evaluate each other's proximity to the flame location.

2. Bluetooth Communication between Robots

Bluetooth version 2.0 protocol feature is available in the intelligent brick of the LEGO MINDSTORMS NXT 2.0 which can be utilized to perform communication between more than one LEGO bricks and computer. Following the normal standard of Bluetooth communication for this prototype, the brick/robot which starts the communication at first is said to be a Master and the brick/robot which receives the message is said to be a Slave.

3. Localization and Obstacle Detection

The robot which qualifies the condition of moving towards the flame, will perform two tasks – one is updating its position using the aforementioned localization technique and the other is to perform obstacle detection. Here, the goal of obstacle detection will continuously be performed by the Ultrasonic sensor mounted on each robot which will detect an obstacle within 10 centimeters ahead of it. If any obstacle is detected in the path towards the flame, the robot will change the direction of movement until there is no obstacle detection and will move back to the loop of moving towards fire.

4. Returning Back to the Initial Position

As soon as the temperature exceeds the maximum limit already set in the algorithm, for example 40°C (as we are using candles as fire source), it will turn around and return back to its initial position using new position data i.e. x_{new} and y_{new}. This strategy is considered because the fire extinguishing objective is out of the scope of this prototype.

IV. Programming Flowcharts and Graphical Representation of Algorithm

The programming flow of two mobile robots is described separately, one acting as the Master NXT Robot and the other acting as the Slave NXT Robot a shown in Fig. 2 and Fig. 3 respectively.

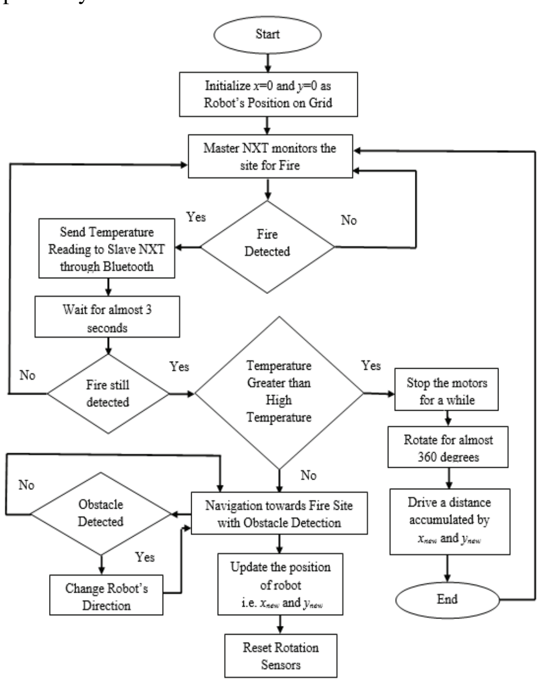

Fig. 2. Master NXT Robot

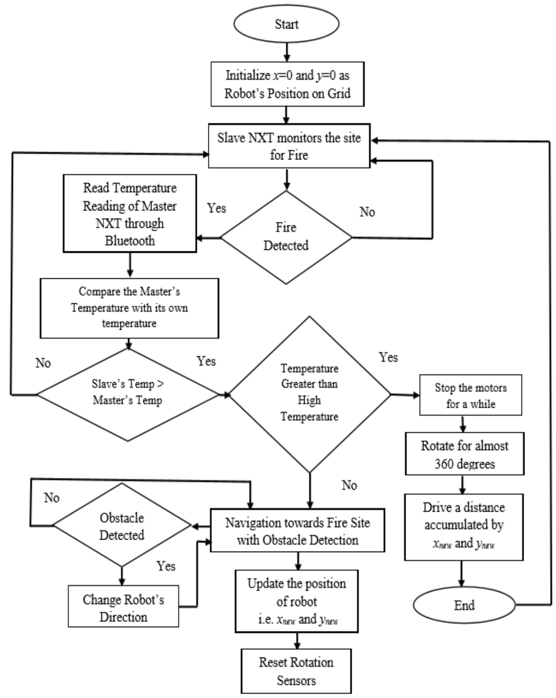

Fig. 3. Slave NXT Robot

Both of the flow charts combine four possible site scenarios:

1. Case-1: No fire detected.
2. Case-2: The Master detects a fire.
3. Case-3: The Slave detects a fire.
4. Case-4: Both robots detect the same fire.

These cases are further described graphically in this section. Fig. 4 shows the first case where no fire is detected.

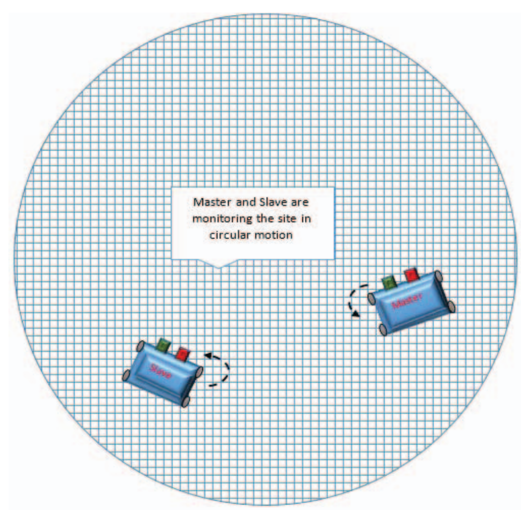

Fig. 4. Case-1: No fire detected

Fig. 5 shows the second case in which only the master detects the fire and the slave is in a position that cannot detect the fire.

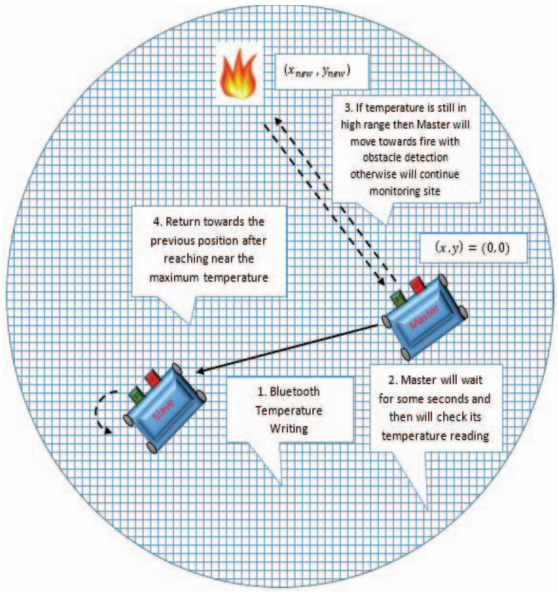

Fig. 5. Case-2: Master detects a fire

Fig. 6 shows the third case in which only slave detects the fire and master is in another position where it cannot detect the fire.

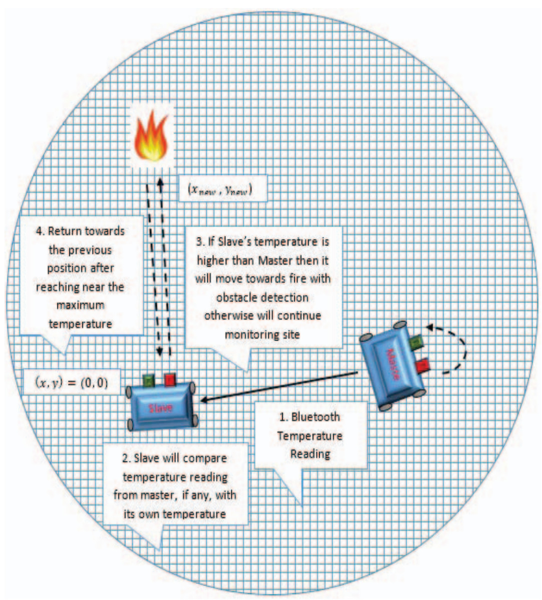

Fig. 6. Case-3: Slave detects a fire

Fig. 7 shows the fourth case in which both robots detect the same fire at simultaneously.

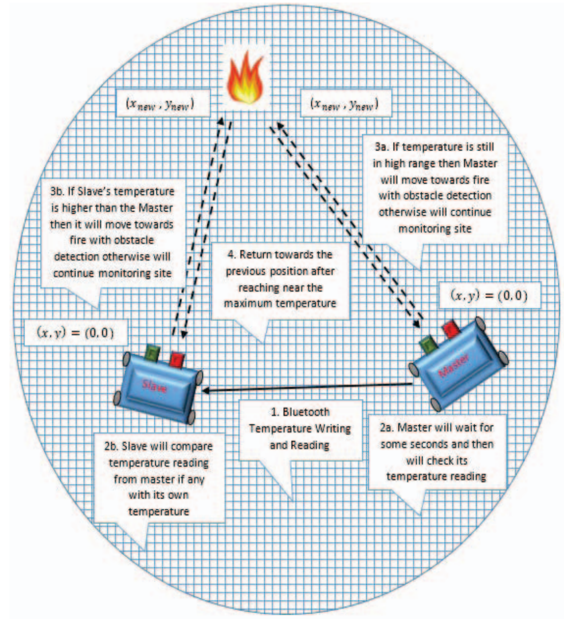

Fig. 7. Case-4: Both Robots detect a fire at the same time

V. RESULTS AND DISCUSSION

Localization of two fire detecting mobile robots has been described in detail using a theoretical description, programming flowcharts and graphical representation in the previous sections of this paper. As mentioned in section IV, there are four main cases like Case-1, shown in Fig. 4, describes the situation when no fire is detected. Therefore, the robots will continue their circular movement. Case-2, as shown in Fig. 5, demonstrates the situation when only the Master Robot detects the fire and as soon as it detects the fire, temperature reading of Master NXT is sent to the Slave NXT which will be compared with Slave's temperature and then almost three seconds of delay is provided to sense a decline in Master's temperature reading assuming that if the Slave has reached/extinguished the fire in a condition of its closeness to the fire site. Since the Slave is in opposite direction, after waiting for a delay, Master will move towards fire site with obstacle detection and will return back to the initial position as soon as it reaches the highest set temperature. Case-3, as shown in Fig. 6, defines that only the Slave Robot has detected the fire. It will first read its mailbox for any temperature readings from the Master Robot. Since the Master has not detected the fire yet then there will not be any readings, so the Slave will proceed towards fire and follow the same steps as Master did in the previous case. Case-4, as shown in Fig. 7, demonstrates the situation when both robots detect the same fire. This situation depends on the temperature readings of both robots, whichever robot is near to fire site will attain the high temperature and will proceed towards fire site. This paper discusses four scenarios for detecting the fire, however one more scenario can be considered and implemented using the same prototype i.e. if both robots detect the fire in different locations at one time then Master and Slave robots will perform the same algorithm steps as shown in the flowcharts and Case-2 and Case-3 respectively.

VI. CONCLUSION AND FUTURE SCOPE

In this work, a model for two fire identifying mobile robots was designed and implemented with the LEGO MINDSTORMS NXT 2.0 kits on an emulated fire site, which can be similarly utilized for multiple robots. For the stable and controlled movement of each robot two servo motors are used. The essential sensors used for this model are: (1) Ultrasonic Sensor and (2) Thermal infrared (TIR) Sensor. An optimal way of obstacle detection is provided by the ultrasonic sensor and fire detection is performed by the TIR sensor by sensing the body temperature of the flame source while movement of robots in circular motion. The model source of flame/fire used in this prototype was candles. In addition, during the complete working of this model algorithm, both robots remain known about their own estimated position which information helps in allowing the movement of robot back to its reference point approximately after attaining the maximum closeness allowed to the fire. For the comparison that which robot (Master or Slave) is nearer to the flame, Bluetooth communication protocol was utilized to share the temperature readings between them. All the anticipated aims and objectives of this prototype were achieved while the Real time run implementation was performed.

However this proposed model executes the intended tasks very well, some limitations are also need to be addressed. TIR sensor is the only compatible temperature sensor to be implemented with LEGO MINDSTORMS NXT which is likely to pose the Line of Sight (LOS) problem while detecting body temperature of flame source. The ultrasonic sensor which is accompanied with the LEGO NXT kit also demonstrates the same issue while spotting the obstacles. The built-in feature of Bluetooth in the LEGO MINDSTORMS NXT 2.0 also didn't establish an effective two-way communication between the robots.

On a future perspective, this model can be utilized for the real time application development for designing the multiple fire extinguishing mobile robots for the sites which have serious fire hazard security concerns. Focusing the shortcomings of this model, usage of enhanced quality sensors is required while implementation in real world domain. Integration of more than one temperature sensor in a robot can help in locating multiple fires at a time and this scenario can be an added feature to the proposed prototype. Wi-Fi feature can be introduced in the progressive work to ensure two way communication between robots and it is also suggested that Wi-Fi communication be utilized as that feature can provide for the development of the prototype with the introduction of more robots leading towards an enhanced centralized system for surveillance of fire hazard.

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