Design and Implementation of Fully Autonomous Fire-Fighting Robot for a Small House Model

J. Reinhart, V. Khandwala, T. Shah, J. Young, L. Ross
R. Delica, F. Angus, J. Burford, B. Lynch, R. Pollard
Department of Electrical Engineering and Computer Science
Florida Atlantic University, Boca Raton, FL 33431
Email: rit.pollard@ieee.org

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ABSTRACT

This paper presents an overview of the design and the implementation of the fire-fighting robot. This project is aimed to assist firefighters in a fire ground evolution and could be an essential tool towards the risk reduction that the firefighting crew has to take. The robot is used in competition at IEEE SoutheastCon 2003. The design strategy is focused on full autonomy, low cost, and optimum navigation algorithms of the robot. In the competition the robot's efficient navigation and fire detecting and extinguishing capabilities, will be tested in a simulated environment that will take place in a small house model. The key design elements of the robot to be discussed include: the assembly and construction of the robot hardware, the processing algorithm based on the sensors response, and the navigation algorithm that will enable the robot to find an efficient path in and out of the house model.

1. INTRODUCTION

The primary objective of this project is to design and implement a firefighting robot that will fulfill the requirements of the IEEE 2003 SoutheastCon Hardware Competition. The fully autonomous robot will navigate through a predefined floor plan, (subject to tolerances), then locate and extinguish a mock fire. A bright red LED simulates the fire. The competition objective is to successfully search for and find the location of the fire. The robot must then extinguish it in the shortest possible time, subject to other provisions. The robot is based on the Mekatronix TJPro™ robot kit due to its low cost and versatility. The Motorola HC11 microcontroller provides control and communication for the robot and utilizes the interactive C programming language. The robot is driven by two modified servo motors that power the drive wheels. Several sensors are mounted on the robot to assist its navigation and to detect the mock fire. The Final version of the robot and the floor plan structure are shown in figure 1 and 2.

2. SYSTEM OVERVIEW

An overview of the main functions is shown in figure 3. It consists of sound detection, navigation through corridors, extinguishing fire, and escape function for returning to home area. Transmission of a 1500 Hz audio signal designates the start time of the competition. When the sound is detected, the sound detector sends an output signal to the microcontroller to initiate a clock and shift control. Navigation through the

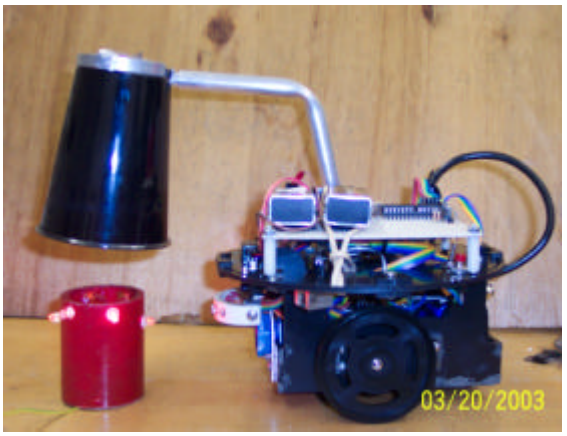


Figure 1: Final version of robot

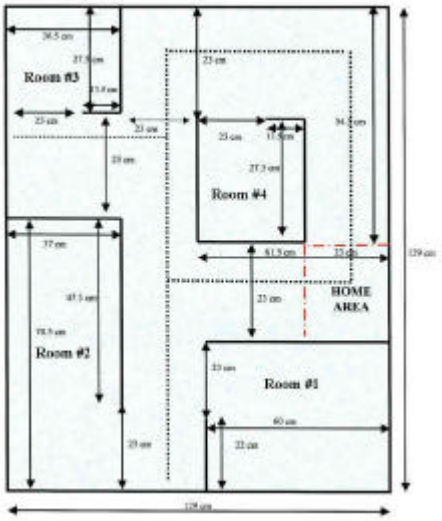


Figure 2: Floor plan

corridors utilizes the line follower system. Simultaneously, the ultrasound guidance system is being utilized to search for a room entrance. Once the fire is detected, navigation is terminated and the fire extinguish function is activated. The fire extinguish function consists of two parts: positioning of the robot to a pre-determined distance so to match the length of the arm and arm movement: descend the arm down to extinguish the fire, and ascend the arm back to the original position. When the fire is contained, the escape function is activated and the robot returns to the home area using the shortest possible route.

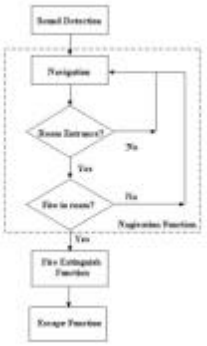


Figure 3: An Overview of the Main Function

3. SOUND DETECTION

Transmission of a 1500 Hz tone triggers the start time of the competition. The tone can be transmitted anytime within 30 seconds of the "hands off" warning. The tone detector is comprised of two stages: a pre-amplifier stage and a tone decoder stage as shown in figure 4.

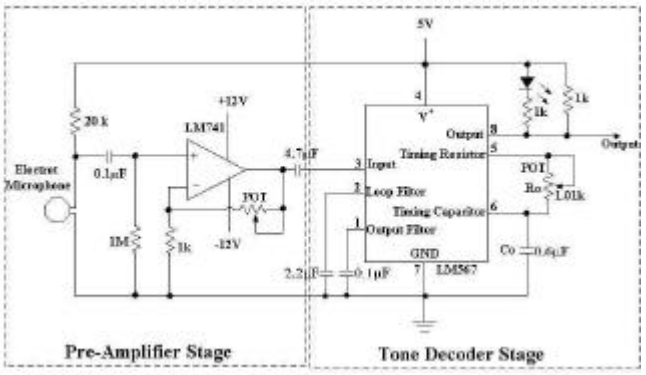


Figure 4: Sound Detector Circuit

The pre-amplifier stage receives an audio signal from an omni-directional condenser microphone. The microphone signal is then fed into a general-purpose operational amplifier, LM741. The LM741 then amplifies the signal to meet input level specifications of the general-purpose tone decoder, LM567. A 1MΩ resistor is used to prevent any signal from feeding back into the microphone. When the input signal is within the desired passband, it provides a saturated transistor switch to ground. The sound decoder consists of an I and Q detector driven by a voltage controlled oscillator. The voltage controlled oscillator center frequency, f_0, is given by (eq.1).

$$\mathbf{f_o} = \frac{1}{1.1\mathbf{R_o C_o}} = \frac{1}{1.1(1010)(0.6\times10^{-6})} \approx 1500 \ \text{Hz} \qquad \text{(eq. 1)}$$

4. NAGIVATION

Navigation function consists of guidance of the robot through the corridors and search for room entrances. The several sensors utilized to assist the navigation are shown in figure 5 and 6. The ultrasonic sensors, S1 ~ S3 are located in front and each side of the robot, and the phototransistor detectors, L1 ~ L5 are located under the robot facing toward floor.

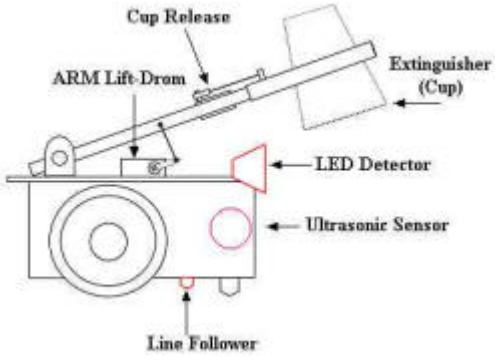


Figure 5: Robot SideView

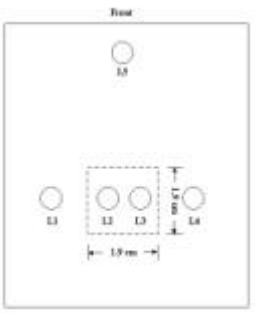


Figure 6: Line Flower Sensor Location

The line follower sensor, L1 ~ L4 are used for an error correction purpose and L5 is used to helps assist decision-making at any intersections of the corridors. The flowchart shown in figure 7 describes the navigation algorithm.

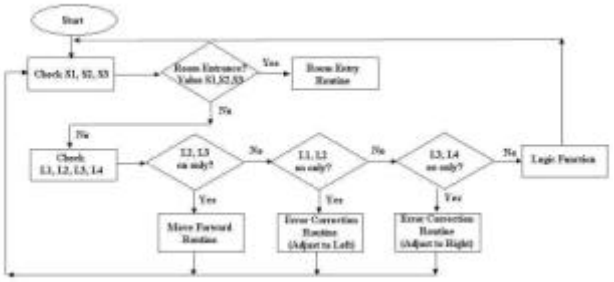


Figure 7: Navigation flowchart

While the distance between the robot and walls are evaluated using the ultrasonic sensors, S1 ~ S3 for searching a room, the intensity of the received lights are checked for following the white line on the corridors. If the robot deviates from the white line, depending on the conditions sets in Figure 7, an error correction is performed so that the robot will remain straight on the white line. When the robot reaches any intersections, the logic function is executed. The logic function flowchart describes this process in figure 8.

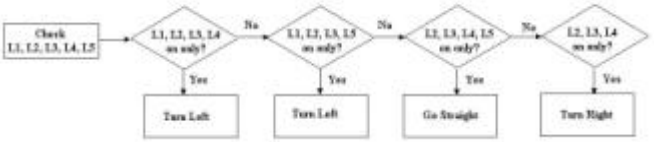


Figure 8: Logic Function Flowchart

The logic function is a set of general rules that applies for the decision-making process at the intersections. The rule is made, so that left turn is always favorable.

Navigation of the robot through the corridors relies on the line follower system, which is comprised of two stages: emitter/detector and comparator. The emitter/detector stage utilizes five LED and phototransistor pairs. Each LED and phototransistor pair is positioned in such a way so that while the LED emits light, the phototransistor detects the reflected light from the floor and outputs the signal to a comparator, LM339. The amount of light intensity received determines the current flow through the phototransistor. The comparator stage compares the four independent input signals and determines the output to be either on or off. Each input voltage from the detectors is compared to a reference voltage set by a potentiometer. The output of the comparator has two stages: high (1: disconnect) and low (0: ground). The potentiometer allows adjustment for obtaining optimal values dependent on reflectivity and ambient light. The circuit is shown in figure 9. The series resistor, 1k ohm, is connected with the LED to control current flow and to prevent exceeding maximum allowable current. The phototransistor detects reflected light between the floor and LED. When the detector is detecting more light, the current flow increases. Thus, the voltage to the minus input of the comparator becomes low.

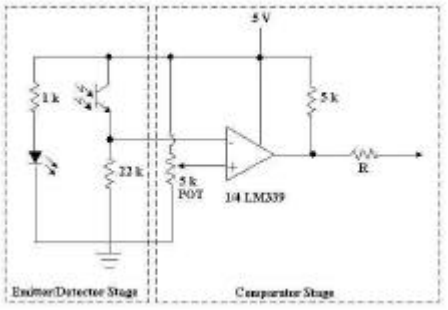


Figure 9: Line Follower Circuit

When the voltage becomes lower than the reference voltage controlled by the potentiometer, the comparator is grounded (0: low stage). When the detector is not over the white line, the detector detects less light. The current flow through the detector is lower, thus the voltage to the input of the comparator becomes high (1) and the output is disconnected. The 5k resistor provides a path between 5v and the output of the comparator. The different value of resistor, R is selected for each line follower circuits in order to differentiate which sensor is on or off at any given time.

The search for a room entrance relies on the ultrasonic guidance system, which consists of a set of a transmitter and a receiver at 4k Hz. Time for a signal to come back to the receiver represent location of an object. The system works best when the object surface is perpendicular to the sensor.

5. FIRE EXTINGUISH

The fire extinguish function comprise of two parts: positioning of the robot to a pre-determined distance from a fire, descending of the arm to extinguish the fire, and ascend the arm back to the original position. The positioning of the robot utilizes the LED sensors shown in figure 3.

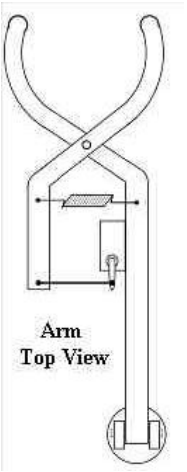


Figure 10: Robot Arm

There are five LED sensors mounted on an arch shape support that is placed on the horizontal plane at front section of the robot. The detection of the LED is sensitive to the ambient light, thus the optimum output values are recorded before the competition and the threshold value used in the program is adjusted accordingly. It will detect the simulated fire and allow the robot to carefully position itself to a predefined distance from the simulated fire source. Once the fire is located and the robot is in position, the robot's arm shown in figure 10 will descend and drop a common sized paper cup over the LED candle, thus effectively extinguishing the flame.

6. ESCAPE FUNCTION

Upon completion of the fire extinguish function; the microcontroller receives a signal and shift control to execute the escape function. The escape function flowchart is shown in figure 11.

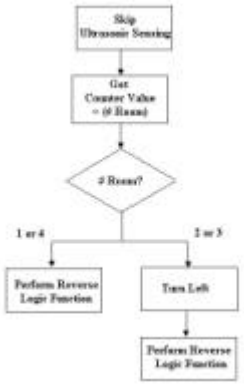


Figure 11: Escape Function Flowchart

During the search for entrance of room, the counter is incremented as the number of rooms is searched. The counter value identifies in which room the robot is located upon extinguishing the fire. Given the counter value, the navigation algorithm is executed using reverse (right favorite rule) logic function that ensures optimum (shortest) path returning to the home area. In case the counter indicates 1 or 4, that is when the fire is detected in room 1 or 4, the escape function is performed solely using the reverse logic function. In case the counter value indicates 2 or 3, the robot must turn left first and then perform the reverse logic function.

7. SOFTWARE TOOL

Software development utilizes the "Image Craft Development Tools" (ICC11) shown in figure 1. The tool facilitate conversion of instruction written in the 'C' into 'machine /assembly' language that is recognized by the microcontroller. This is an efficient tool to employ, since it does not require learning different types of instruction used for different types of microcontroller. The ICC11 is compatible with family of HC11.



Figure 12: Example of IC11

8. SUMMARY AND CONCLUSION

The fire-fighting robot for a small house model was designed and implemented. The aim of this project was to build fully autonomy, low cost, and optimum navigation algorithms of the robot. The reliability of the robot performance was also an important issue considering the real fire-fighting scenario. The fundamental problem we encounter was troubleshooting several loose connections caused by transporting the robot to a different location. Troubleshooting can be tedious and time consuming. Thus, the fabrication of the circuit board is important in order to maintain reliable performance of the robot. In addition, use of better selection of products and components, and conduct further testing to obtain repeatable sensors readings can contribute to further enhancement of the robot performance.

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