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Development of a Low-Cost Autonomous Fire Detection and Suppression Robot

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Abstract : *Fire accidents in the home, industrial and commercial environment can result in massive loss of human life and property. It is of the utmost importance to detect and extinguish fires at the very earliest stage to minimize the damage and the resultant harm. The paper presents an Arduino based fire fighting robot which is capable of detecting the direction of the fire, moving towards it and using a water pump to put out the fire. The robot proposed in this work comprises of an Arduino UNO controller, three flame sensors (one at the left, one at the center and one at the right) to identify the location of the fire in the three different directions, an L298N motor driver and four DC geared motors for movement of the robot (forward, backward, left and right), a relay module to switch on the water pump and a water pump to cut and extinguish the fire. The flame sensors provide the data regarding the direction of the fire to the Arduino which then makes the decision as to how the robot should move based on the sensor readings. If the fire is detected on the left or the right side of the robot, the robot will move in the direction of the detected fire. If the fire is detected at the front or the center of the robot, the robot will move forward and the water pump will be turned on via the relay. If none of the sensors detect a fire signal, the robot will stop and the water pump will be switched off. The information regarding the operation of the robot (sensor readings, robot movement and pump status) is sent to the Arduino Serial Monitor for the user to view. The proposed fire fighting robot can provide a low cost embedded system level solution for the basic autonomous detection and suppression of fires and can also help in reducing the human effort required for fire suppression at the initial stage. It is possible to add features such as a Wi-Fi module to transmit the information about the fire status and the location of the robot over the internet. Obstacle detection and fire suppression based on distance can also be incorporated into the robot.*

Keywords: Fire fighting robot, Arduino UNO, flame detection, autonomous navigation, L298N motor driver, relay module, water pump, embedded system

I. INTRODUCTION

Fire is a big problem for houses and factories and other buildings. Damage can be huge and sometimes people get hurt. Fires spread fast so it is hard for anyone to reach them in time. The usual way is someone going in with gear but that puts the person right in the heat and smoke and bad gases. So there is a need for robots that can handle some of this instead and that is what a lot of projects are trying to do now.

Recent stuff with small controllers and sensors has made it possible to build robots that find fires and put them out with less help from people. The one in this project uses an Arduino uno along with three flame sensors placed to catch fire on the left side or straight ahead or on the right. There is also a motor driver and four motors plus a relay that turns on a water pump. The idea is the robot spots the flame and moves toward it then starts the pump if it is right in front. The Arduino reads the sensors all the time and decides what to do next. Left sensor on means it turns left. Right one means

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turn right. Center one means go straight and the pump comes on through the relay. Nothing detected and it just stops. It is simple and does not need any camera work. The motors are run through the L298N driver so the robot can go forward or turn by changing the speed on each side. The relay keeps the pump power separate so it does not pull too much from the Arduino pin.

There is also serial output that shows the sensor states and what the robot is doing. That helps when testing to see if everything is working right or if a sensor is slow or a motor is going the wrong way. It seems useful for figuring out small issues during setup. The whole thing is meant to be cheap and easy to put together as a demo or for learning how these parts work together. Components can be checked one at a time which makes changes simpler later on. Flame sensors do not always pick up things from far away though and light around the room can mess with them. There is no distance check so the robot might get close or stop too soon. Water only works for certain fires anyway so this is really just for lab tests and not something that replaces real equipment. It could maybe add obstacle sensors or better movement logic later and some more runs to check how well it actually finds flames and turns. That might help but it is not settled yet. The rest of the paper goes over the parts and the code and some tests that were done.

II. RELATED WORK

Fire detection has moved from people putting out fires by hand to systems that can spot trouble and react with less help from anyone. Sensors and microcontrollers get put into robots so they work cheaper and respond quicker while keeping people away from smoke and heat. It seems fixed detectors only give warnings and stay put so they do not chase the source or put anything out. That gap pushed work on robots that move and carry their own suppression parts. Arduino setups show up often in these student projects because the board is straightforward and lets you connect several inputs and outputs without too much trouble. The chip takes readings from the sensors and sends signals to motors and other pieces. Still the whole thing only works as well as the sensors stay reliable and the motors get enough power.

Placing flame sensors left center and right lets the robot know roughly which way the flame sits so it can turn toward it instead of just stopping. One sensor alone would not give that direction cue. Motor drivers like the L298N let the board run the wheels forward or turn them while a relay switches the pump. When the side sensors trigger the robot rotates and when the middle one sees flame it rolls ahead and starts spraying. If nothing shows up it just sits there with the pump off.This lines up with some earlier work. Adilshah made a similar three sensor robot with geared motors and spraying. Oyelami added an ultrasonic piece for avoiding obstacles while keeping the flame detection. Kolajo brought in smoke sensing plus phone alerts on top of the basic robot. Chenchireddy used infrared for obstacles along with the flame and pump parts. I think adding one more sensor type might help but the basic version already covers the main movement and spray actions.

Review of existing research

- Adilshah et al. (2022): Proposed an Arduino based autonomous firefighting robot using three flame sensors, geared motors, and a water-spraying mechanism. This work is closely related to the proposed project's directional flame detection and automatic suppression approach.
- Oyelami et al. (2024): Developed a low-cost firefighting robot using three flame sensors, an ultrasonic sensor for obstacle avoidance, and additional components for directional navigation. Their work demonstrates how multiple sensors can support fire detection and robot movement.
- Kolajo et al. (2024): Presented an autonomous fire-extinguishing robot incorporating an Arduino UNO, flame and smoke sensors, ultrasonic obstacle detection, water spraying, and SMS notification. Their system extends basic fire suppression with additional sensing and remote alerts.
- Chenchireddy et al. (2025): Presented an Arduino-based firefighting robot incorporating flame detection, motor control, a water pump, and infrared obstacle detection. The study provides a relevant example of integrating fire detection, navigation, and suppression in a single robotic platform

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III. PROPOSED ARCHITECTURE

Propose will not significantly reduce the multiplier's operating speed.

IV. METHODOLOGY AND WORKING PRINCIPLE

A. System Methodology

The proposed system uses an Arduino UNO microcontroller to detect flames navigate and spray water. The robot has three flame sensor modules set to the left, center and right a motor driver, four DC geared motors, a relay module and a water pump. The flame sensors send signals to the Arduino, which reads those signals and decides how the robot should move and when the pump should run. At first the microcontroller sets the sensor pins to input mode and the motor driver and relay pins to output mode. While the robot is active the three flame sensors watch their directions all the time. The Arduino reads those signals follows set decision rules and sends control signals to the motors and the water pump. The L298N motor driver turns the DC motors in the direction and the relay module turns the water pump on or off depending on where the flame is. The system uses a rule‑based control method where the robot moves based on the direction of the flame. This simple and inexpensive approach lets the robot perform autonomous firefighting without needing complicated image processing or wireless links.

B. Flame Detection And Direction Identification

Three flame sensors are set to watch the center and right directions. Each sensor gives an output that depends on the flame it sees. In this design a LOW output means a flame is present while a HIGH output means no flame is seen. The Arduino reads all three sensor outputs. Turns them into simple detection states. Those states tell the robot which direction the flame is in. Using three sensors gives the robot direction clues so it can choose the movement. This sensor layout allows direction decisions but how far the sensors can see and how reliable they are depends on the sensor type, flame strength, angle and the light around.

C. Robot Navigation And Motor Control

The robot moves thanks to an L298N motor driver that works with four DC geared motors. These motors power the right sides. The Arduino sends signals to the driver to decide which way the motors spin. If the left flame sensor sees a flame the robot turns left. If the right flame sensor sees a flame the robot turns right. If the center sensor sees a flame the robot drives forward toward it. When no flame is seen the robot stops. The navigation is coded with set rules in the Arduino. The controller checks the sensor states. Picks the matching movement command. The exact turning direction depends on how the motors wired and how the signals are set up.

D. Water Pump Activation And Fire Suppression

A water pump sits on the robot to give a fire‑suppressing action. The pump is turned on and off by a relay module that the Arduino talks to. The relay is a switch that lets the low‑power controller control the pump. When the center sensor sees a flame the Arduino tells the robot to go and turns on the relay‑controlled water pump. Water then flows out toward the fire. If the flame is on the left or right the robot turns that way and keeps the pump off. If no flame is seen the robot and the pump stay idle. The pump logic is made to match movement with water release. How well the fire is put out depends on the water supply the pump flow, how far the robot's the fire’s size and type.

E. Control Sequence

The whole operation runs as a loop of sensing and control. First the Arduino reads the outputs of the three flame sensors. Then the controller checks if a flame is there and which sensor sees it. Using those states it makes motor commands. Decides if the water pump should run. The loop keeps going letting the robot react to flame positions.

The main control sequence can be summarized as follows:

1. Set up the flame sensors, motor driver and relay control pin.

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2. Read the outputs, from the center and right flame sensors.
3. If only the center sensor detects a flame move forward. Turn on the water pump.
4. If the left sensor alone sees a flame turn left. Keep the pump off.
5. If the right sensor alone sees a flame turn right. Keep the pump off.
6. If no flame is seen, stop the robot. Turn the pump off.
7. If many sensors see a flame at the time or if the direction is unclear stop the robot and keep the pump off.
8. Repeat the sensing and decision process.

This control plan puts flame detection, motor movement and water pump operation inside one small embedded system. Using rule‑based logic keeps the plan easy to build and suitable, for low‑cost prototype work.

V. CONTROL ALGORITHM AND FLOWCHART

A. Control Algorithm

The firefighting robot works by using a rule-based control algorithm that runs on the Arduino UNO microcontroller. The algorithm reads the signals from three flame sensors that are placed to the left, center and right of the firefighting robot. When the firefighting robot sees a flame in a given direction the microcontroller moves the firefighting robot with the help of the L298N motor driver. Turns on the water pump through a relay module if the center sensor sees a flame.

Step 1: Initialization

The firefighting robot must set the three flame sensor pins to input mode. Set the motor driver and relay control pins to output mode. The firefighting robot should also start the motor and pump in a state.

Step 2: Sensor Reading

The firefighting robot must keep reading the outputs from the center and right flame sensors.

Step 3: Sensor State Evaluation

The firefighting robot must analyze the sensor outputs to find out where the flame is. In the firefighting robot's design a LOW signal means a flame is detected and a HIGH signal means no flame.

Step 4: Centre Flame Detection

If only the center sensor shows a flame the firefighting robot should move forward. Turn on the water pump via the relay module.

Step 5: Left Flame Detection

If only the left sensor shows a flame the firefighting robot should turn left while keeping the water pump off.

Step 6: Right Flame Detection

If only the right sensor shows a flame the firefighting robot should turn right while keeping the water pump off.

Step 7: No Flame or Ambiguous Detection

If none of the flame sensors show a flame or if than one sensor shows a flame at the same time the firefighting robot must stop and turn off the water pump.

Step 8: Repeat the Process

The firefighting robot must keep repeating the sensing and decision steps so that it can react to any change in flame direction.

This algorithm gives the firefighting robot a way to combine flame detection, direction control and water pump activation. The firefighting robot's operation depends on the outputs of the flame sensors and, on the fixed control rules.

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B. Flowchart Description



The flowchart shows the steps that the firefighting robot follows. The firefighting robot starts by initializing the Arduino flame sensors, motors and relay module. The firefighting robot then reads the sensor outputs. Checks the states to decide what to do. When only the center sensor shows a flame the firefighting robot moves forward. Turns on the water pump. When only the left sensor shows a flame the firefighting robot turns left. Keeps the pump off. When only the right sensor shows a flame the firefighting robot turns right. Keeps the pump off. If no flame is. If the sensor readings are unclear the firefighting robot. Keeps the pump off. After the firefighting robot does the chosen action the firefighting robot goes back to reading the sensors and repeats the cycle. This continuous loop lets the firefighting robot react to flame detections while it is working.zz

VI. CONCLUSION

This work presented the design and implementation of power efficient soft-logic multiplier architecture for FPGA based FIR filter application. The proposed architecture integrates Radix-4 Modified Booth encoding, a structural selective Dadda reduction network and a ripple carry adder for performing signed multiplication without using dedicated DSP slices. The multiplier has been successfully incorporated into a 9-tap transpose-form FIR filter and implemented using Verilog HDL on Xilinx Vivado Design Suite. Post-implementation results show efficient FPGA resource allocation, successful timing closure and low estimated on-chip power consumption. The proposed architecture achieves a good trade-off among computational performance, hardware complexity and implementation efficiency, thus being a good choice for high-performance FPGA-based digital signal processing applications.

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