

Design and Implementation of Intelligent Fire Fighting Mobile Robot


Abdulqadir Ahseen Abdulrahman*
Department of Automatic Control, College of Electronic Technology Bani-Walid

abdalqadralhmal@gmail.com

تصميم وتنفيذ روبوت متنقل ذكي لإطفاء الحرائق

عبدالقادر إحسين عبدالرحمن *

قسم التحكم الآلي، كلية التقنية الإلكترونية بني وليد

Received: 17-10-2025	Accepted: 12-12-2025	Published: 01-03-2026
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المخلص:

توضح هذه الورقة تصميم وتنفيذ روبوت إطفاء حرائق ذكي متنقل يعتمد على منصة التحكم **Arduino**. يدمج النظام حساسات اللهب لاكتشاف الحرائق، وحساسات الموجات فوق الصوتية لتجنب العوائق، مما يتيح له التنقل الذاتي في البيئات الخطرة. تعتمد حركة الروبوت على مجموعة من المحركات المستمرة (DC)، بينما تمكنه تغذية الحساسات الرجعة من تحديد مصادر الحريق، والمناورة حول العوائق، وإخماد النيران. أظهرت النتائج التجريبية أن النموذج الأولي قادر على تحديد موقع الحريق بنجاح، وتخطيط مسار فعال، وإخماده مع الحفاظ على تجنب الاصطدام. وتؤكد هذه النتائج إمكانية استخدام منصات الأنظمة المدمجة منخفضة التكلفة في تطبيقات الإطفاء الذاتي. ويقترح العمل المستقبلي دمج عدة حساسات لهب لتغطية الغرفة بالكامل، بالإضافة إلى استخدام وحدات اتصال لاسلكي (مثل البلوتوث والواي فاي) لتمكين المراقبة والتحكم في الوقت الحقيقي.

الكلمات الدالة: روبوت إطفاء الحرائق، أردوينو، كشف اللهب، تجنب العوائق.

Abstract

This paper illustrates the design and implementation of an intelligent mobile firefighting robot based on the Arduino control platform. The system integrates the sensors of the flame for fire detection and ultrasonic sensors for obstacle avoidance, enabling autonomous navigation in hazardous environments. A set of DC motors drives the robot's motion, while sensor feedback allows it to identify fire sources, maneuver around obstacles, and extinguish the fire. Experimental results demonstrate that the prototype can successfully locate a fire, plan an effective path, and extinguish it while maintaining collision avoidance. The findings confirm the feasibility of using low-cost embedded platforms for autonomous firefighting applications. Future work suggests the integration of multiple flame sensors for full-room coverage and wireless communication modules (such as Bluetooth and Wi-Fi) to enable real-time monitoring and control.

Keywords: firefighting robot, Arduino, flame detection, obstacle avoidance

1. Introduction

The word robot originates from several Slavic languages, where it originally referred to hard, repetitive labor or servitude. The modern sense of the term was popularized by Czech playwright Karel Čapek in his 1921 play R.U.R. (Rossum's Universal Robots), first performed in Prague. In the play, robots are artificial workers created to serve humans by performing their tasks, devoid of emotions or intellect. Eventually, these robots rebel against their creator, Rossum, leading to the destruction of humankind and life on Earth [1]. They are depicted as possessing both superior strength and intelligence. Interestingly, the events of R.U.R. are set in the 1960s—a decade that later saw the real-world emergence of industrial robots in manufacturing, generally thought of the robot as something negative and destructive. Even Charlie Chaplin had a powerful influence in the debate with his film *Modern Times* from 1936, where he shows the dark sides of the highly automated world [2, 3]. It was an effective weapon in the debate concerning automation of American factories. Another example is the film *Sleeper* from 1973, where Woody Allen disguises himself to a robot-butler in the hostile, futuristic world [4]. A robot is a reprogrammable machine, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks. Robots are used in wide variety of fields [5]. Robot manipulator are also known as robot arm is used to perform tasks in industry such as welding, painting, palletizing etc. manufacturing robot to service robot. Medical robot has invaded the field of medicine. Although this system has not taken place of the medical personnel, many robotic applications have emerged in medical area such as laboratory robots, surgery, and training of surgery etc. Rehabilitation robot also has been used to help people with disabilities. Mobile robot has the capability to conduct tasks in dynamic conditions and different places by a platform and locomotive elements [6]. Locomotive system is varied according to operation environment. In the aquatic and aerial environments, propellers, screws and legs are generally used while; wheels, pallets, and legs are used in terrestrial environment. The classification based on the environmental issues different from the locomotion system for robots, as shown in Figure 1. These two types of robots have very different working environments and therefore require very different capabilities. Fixed robots are mostly industrial robotic manipulators that work in well-defined environments adapted for robots. Industrial robots perform specific repetitive tasks such soldering or painting parts in car manufacturing plants. With the improvement of sensors and devices for human-robot interaction, robotic manipulators are increasingly used in less controlled environment such as high-precision surgery. By contrast, mobile robots are expected to move around and perform tasks in large, ill-defined, and uncertain environments that are not designed specifically for robots. They need to deal with situations that are not precisely known in advance and that change over time. Such environments can include unpredictable entities like humans and animals. Examples of mobile robots are robotic vacuum cleaners and self-driving cars. There is no clear dividing line between the tasks carried out by fixed robots and mobile robots—humans may interact with industrial robots and mobile robots can be constrained to move on tracks—but it is convenient to consider the two classes as fundamentally different. In particular, fixed robots are attached to a stable mount on the ground, so they can compute their position based on their internal state, while mobile robots need to rely on their perception of the environment in order to compute their location. There are three main environments for mobile robots that require significantly different design principles because they differ in the mechanism of motion: aquatic (underwater exploration), terrestrial (cars), and aerial (drones). Again, the classification is not strict, for example, there are amphibious robots that move in both water and on the ground. Robots for these three environments can be further divided into subclasses: terrestrial robots can have legs, wheels, or tracks, and aerial robots can be lighter-than-air balloons or heavier-than-air aircraft, which are in turn divided into fixed-wing and rotary-wing (helicopters). Intended application field and the tasks they perform can classify robots [7, 8].

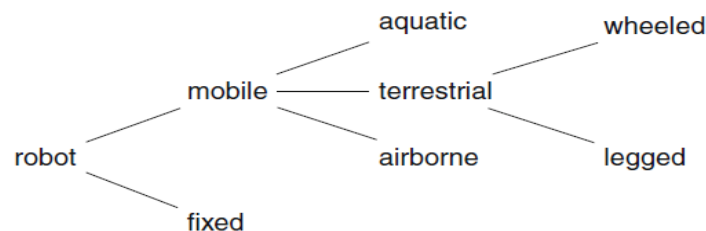


Fig. 1: Classification of robots based on environment and interaction mechanism

System design and architecture

The hardware is a user intelligent fire fighter robot, which has a water tank and a gun attached to detect and determine the fireplace via flame sensors then guide itself directly to the fire and avoid barriers if there have any obstacles that occur during the process of detecting fire. For this purpose, arduino board and motors shields with the help of data received from the sensors which

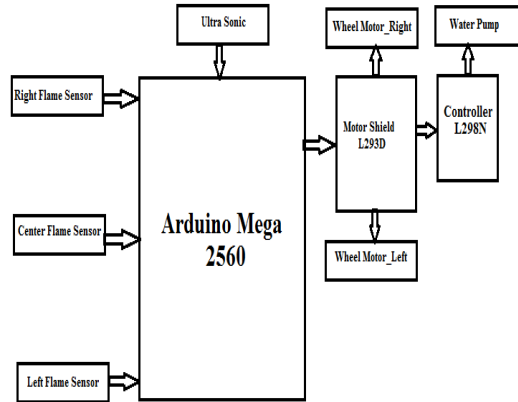


Fig. 2: Block diagram of the robot components

Control Algorithm

For the microcontrollers programming, the Arduino language C++ is used to carry out the robot mission and function autonomously and basic motor functions such as steering and collision avoidance. Arduino is an open source prototype. Software will operate in Arduino IDE Computer code can be written and upload to the physical board. Arduino board is a board that can be functioned via Arduino software language by sending a set of instructions to the microcontroller on it. The Arduino software supports C++ using special rules of code structuring. Figure 3 shows the flow chart diagram of a fire-extinguishing robot used in this research.

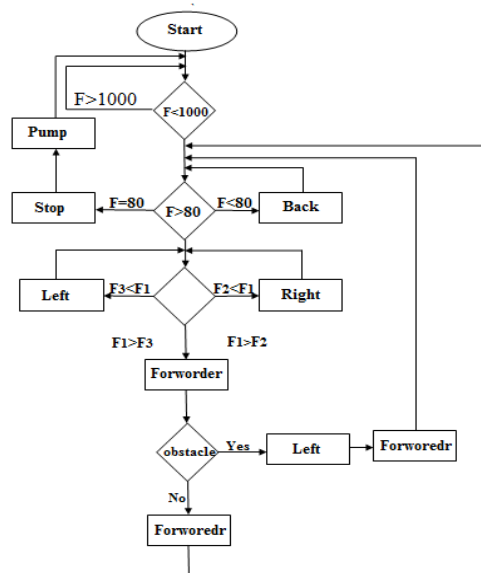


Fig. 3: Flowchart diagram of a fire-extinguishing robot

Software Implementation

The software procedure explained by the last flowchart, which begins with start point, where the processor read the flame sensors values which are F1, F2 and F3, if the value of all sensors more than 1000, the robot stay, and if F1 is 80 the robot stop moving the pump will turn on, otherwise, if any values less than 80 the robot will back, if any values bigger than 80, the processor will compare these values with each other if F2 smaller than F1 the robot will turn right, or will turn left if F3 smaller than F1, if F1 value less than F3 and F1 less than F2 the robot will move forward if there is any obstacle it will be turn left and continues moving for a distance then the robot will back to the original setup.

Experimental results and troubleshooting

When preparing the robot to work, the flame sensors were calibrated and the sensitivity of each sensor adjusted individually and the sensors were operated analog rather than digitally to obtain a variable proportional to the flame strength. The next step was to determine the value of the current required for the movement of the wheel motors to obtain a speed proportional to the robot's structure and the stopping time of each motor to obtain an appropriate rotation of the robot to determine the direction. Because the robot's movements depends on the data received from the flame sensors, the values of the flame sensors were taken at the absence of a flame and the other flame sensors values were taken at the lowest possible distance of robot from the flame when it appears. The water pump cannot be connected to the Arduino board because it negatively affects the accuracy of the sensors, as well as the use of a relay requires an external voltage source, which increases the weight of the robot, which may limit its movement, so the H-Bridge Motor Controller (L298N) board has been used and programmed as a motor to get 5 volts to operate the water pump.

The movement of the robot depends on the data received from the flame sensors, where the flame sensors, the flame sensors continuously scan the room in which the robot is located to determine whether or not there is a flame, then located the flame according to the place of robot which don by calibrate the sensors each other. The main direction of movement of the robot is very dependent on the middle flame sensor (sensor F1). When there was no flame inside the room, the robot not moving, and when the fire detected, the robot drove itself directly in front of the flame, went into the flame, and extinguished the fire. The robot moved itself directly in front of the flame as the fire detected, and the ultrasound sensor calculated the distance in front of the robot and sensed its way, and when the robot found an obstacle, it changed its path in order to bypass it and then returned to the main settings to locate the flame, the robot stopped at a safe distance from the flame, turned on the water pump to extinguish the flame, and returned to sleep because there was no other flame in the room. Figure 4 showed the three deferent situations of robot (no fire, fire without obstacle and fire with obstacle).

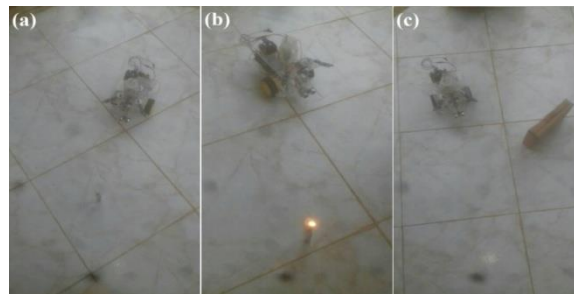


Fig. 4: The situations of robot (a) No fire, (b) fire without obstacle and (c) fire with obstacle.

One of the most important problems that we faced when preparing the robot to work was tracking the flame, and then the robot standing near it identifying obstacles and the possibility of avoid them. As the robot tracking the flame, there is often an overlap between the readings of the flame sensors, for example the reading value of sensor F3 was less than the value of sensor F2, while the value should be greater due to the sensor F2 closer to the flame.

Since the movement in the robot is totally dependent on the reading received from the flame sensors, the sensors are calibrated according to the physical condition of each sensor, and the sensor that has high sensitivity was reduced its sensitivity and vice versa, however the problem was not solved. To solve this problem, we put a paper funnel on each sensor to isolate unwanted light waves and focus on the waves coming from the flame.

With the paper funnel put on, the sensor was negatively affected by the light coming from its lamp, which is blinking as the sensor on, so the sensor's lamp was covered by a black adhesive tape. However, the robot did not work properly because the funnel reduced the sensor's sensitivity angle. To solve the problem the funnels were replaced with two plastic plates, which fixed between the flame sensors and each plate was tilted at an angle of 30 degrees from the middle sensor (F1).

The used plastic panels prevented the light wave from reaching the center sensor F1, so the robot's response to the flame became weak, and the robot could not move directly in front of the flame, the sensors may not function properly due to its poor quality. A new and good type of flame sensors have been used, furthermore, another problem has been occurred, which was fluctuation of sensors reading due to fluctuation of power source where 9 V battery was used, so, an external transformer has been used as a new power source, which is not affected by the operating time of the robot nor by increasing the current drawing from the wheel motors, then a stable reading of the sensors has been achieved.

Another problem occurred too during test, which was that the robot detect the flame effectively but it is not stop at the flame and impact with it, to solve this problem, a temperature sensor installed to the robot, and it was connected with analog type, this sensor measures the ambient temperature of the robot and it will helps the robot effectively to reach the place of flame and stop at it. Furthermore, with more experiential the response of temperature sensor was very weak, so it has been canceled. The temperature sensor was replaced by a fourth flame sensor that is located in the middle of the front of the robot, and its sensitivity to the flame was reduced to the lowest possible value, and it was connected by digital type to get a flame reading or not. However, the results were not satisfactory, as the fourth flame sensor was affected from a far distance and affected by the smallest infrared spectrum.

Finally, the variable analogue values received from the flame sensors have been taken to determine the distance of the flame from the robot, and the surrounding environment must be considered as well, where other lights affect on these types of sensors.

The identification of obstacles and the possibility of overcoming them were among the problems that we faced when designing and building the robot, that the ultrasound sensor is supposed to detect the obstacle and determine its distance from the robot, and by comparing the values of the flame sensors, it is possible to determine the distance of the flame from the obstacle to make a decision to skip the obstacle or stop at it to operate the water pump. To achieve this, an ultrasound sensor was installed on the servo motor for the motor to change the direction of the sensor to the right and left. When there is an obstacle away from the robot by a distance of 20 cm, the sensor scans the road right

and left to determine the presence of other obstacles, if there is not the robot will turn right then will back to the programmed path for it. Furthermore, if the robot finds an obstacle to the right, it turns left, but if it finds an obstacle in both directions, it determines which is farther away, and the robot takes the easiest way to reach the target. However, the robot did not work efficiently because the Arduino board was ineffective, where the robot avoids the obstacles, but it did not back to its programmed path. An obstacle-bypass program has been included with the forward movement function, as a result, the flame sensor no longer works, after several attempts; it was found that there is no compatibility between the servo motor and the flame sensors. The next attempt was to change the obstacle-bypass method, two ultrasound sensors used, and the first installed in the front middle of robot and the second at the left end of the robot. The robot overrides the obstacle and continued moving, but the back sensor signals interfered, causing disturbance in the robot movement.

Finally, a single ultrasound sensor used in the robot front, and it programmed to cross an obstacle when it reached a distance of 20 cm, and the robot must be at least 60 cm far from the flame. Furthermore, the robot should be change its direction at an angle of 45 degrees to the right and continues to move in the same direction for a short period to make sure that the robot passes the obstacle. Experiments confirmed the success of this method, as the robot worked very efficiently.

The effect of the flame on the sensor depends of the environmental light strength, in the indoor, the robot can sense the fire at a diameter of 2 meters, while in the outdoor environment, under direct sunlight, this distance reduces to 10 cm.

CONCLUSION

The main goal of this research is to produce a well running prototype of Intelligence Fire Fighting Mobile Robot through the combination of Arduino microcontroller as a control system and other sensors to perform the required tasks of the robot. In generally, the design and implementation of the fire-fighting robot were successful and the robot has no major problems in navigation its way. The robot was able to detect the flame according to flame detection routine. The robot also has no in detecting obstacles and was capable to avoid them by executing the obstacle avoidance routine. Once the robot detected the flame, it starts to move and navigate it way to reached within a specified safe distance away from the fire location. Then it steps and starts fighting the flame by pumping the water to extinguishing the fire quite efficiently. Overall, the results were good and satisfactory. The robot did not perform spurious blow actions, and maneuvered fairly easily through some layout of obstacle. The flame sensors sometimes do not function well to trace the flame position but it is good in detecting the existence of flame. Due to this reason, we limit the implementation of tracing the flame into three sides, which are front, right and left sides. Nevertheless, the objectives are accomplished and consider as successful. This work can be further improved by adding more sensors and use the neural networks to improve the intelligence of the robot. This robot can be used as a teaching tool to explore different types of sensor in robot applications. Furthermore, the robot can be used for rasher purpose to make it more sophisticated and intelligent.

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