Autonomous Fire Hazard Mitigation Robot with GSM Alert System

Embedded Systems and IoT Lab
Department of Computer Science and Engineering

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Chapter 1

Introduction

1.1 Introduction

Fire hazards pose a significant threat to life, property, and the environment, often spreading rapidly before emergency responders can arrive. Conventional fire detection systems, such as smoke alarms and manual extinguishers, rely heavily on human intervention, which may be delayed or unsafe during emergencies. Recent advances in embedded systems, robotics, and wireless communication have made it possible to design autonomous solutions capable of detecting, responding to, and mitigating fires in real time. Integrating fire detection sensors, autonomous navigation, and GSM-based alert mechanisms can provide both immediate suppression and remote notification, ensuring a faster, safer response to fire incidents.

In many residential, industrial, and commercial settings, early fire detection alone is not enough to prevent significant damage. Delayed human intervention, inaccessible fire locations, and a lack of real-time communication with emergency services can lead to uncontrollable fire spread. The absence of a low-cost, mobile, and automated system that can detect fire, suppress it, and notify concerned authorities limits the efficiency of current fire safety measures. Therefore, there is a need for an **"Autonomous Fire Hazard Mitigation Robot"** equipped with a GSM alert system to detect fire, navigate toward the hazard, initiate suppression, and instantly alert responsible personnel, reducing response time and minimizing damage.

1.2 Motivation

The motivation for developing this project stems from the need to bridge the gap between early fire detection and rapid, effective mitigation. While fire alarm systems can detect hazards, they still require human presence and quick decision-making, which may not always be possible in dangerous or inaccessible areas. By leveraging embedded systems, autonomous robotics, and GSM communication, it is possible to design an intelligent, mobile unit capable of detecting fires, navigating toward the source, and initiating suppression without human intervention.

From a computational perspective, this project presents an opportunity to integrate multiple real-time systems—sensor data acquisition, autonomous navigation algorithms, actuator control, and wireless communication—into a single embedded platform. The challenge lies in achieving reliable decision-making under time-critical conditions, which makes it both technically stimulating and impactful.

Solving this problem benefits us not only by enhancing our skills in robotics, embedded programming, and sensor integration but also by contributing to a practical solution that can save lives and property. Successfully implementing such a system will deepen our understanding of real-world automation challenges, improve our ability to design fault-tolerant embedded systems, and prepare us for tackling complex engineering problems in the future.

1.3 Objectives

The primary objectives of this project are:

1. To design and develop an autonomous mobile robot capable of detecting fire hazards using appropriate sensors (e.g., flame).
2. To implement a navigation system that enables the robot to autonomously move toward the detected fire source while avoiding obstacles.
3. To integrate a fire suppression mechanism (e.g., water pump) that can be activated automatically upon hazard detection.
4. To incorporate a GSM-based communication system that sends real-time alerts and location information to predefined contacts or authorities.
5. To ensure system reliability by designing an embedded control system that operates effectively under time-critical and hazardous conditions.
6. To develop a cost-effective and scalable prototype that can be adapted for use in residential, industrial, and commercial environments.

1.4 Feasibility Study

Several research and practical implementations have demonstrated the effectiveness of integrating robotics, embedded systems, and GSM communication for fire safety applications. However, many existing solutions either focus solely on fire detection or require manual intervention for suppression, limiting their effectiveness during rapid fire spread.

A study by Swapna Raghunath et al. [1] developed an **Arduino-based fire-fighting robot** equipped with flame sensors, an automated water-spraying mechanism, and a GSM module to send SMS alerts to the user. The system successfully detected fire hazards, navigated toward the source, and suppressed the fire while simultaneously notifying the concerned person. This research confirmed that low-cost embedded systems can combine autonomous action and remote communication to enhance fire safety.

The work in [1] demonstrated that using affordable hardware such as Arduino, flame sensors, motor drivers, and GSM modules can result in a functional and reliable fire mitigation system. It also highlighted the importance of combining hazard response with immediate alerting to minimize losses.

The methodology presented in [1]—integrating hazard detection, autonomous navigation, suppression mechanisms, and GSM-based alerts—serves as a strong technical foundation for this project. By enhancing the navigation algorithm, improving sensor fusion for detection, and optimizing suppression control, the proposed work aims to build upon this foundation for improved performance and scalability.

Given the success of [1] and the availability of low-cost embedded components, it is feasible to develop an **Autonomous Fire Hazard Mitigation Robot with GSM Alert System** that can detect, approach, suppress fires, and notify authorities in real time, providing a practical and scalable fire safety solution.

1.5 Gap Analysis

The study by Raghunath et al. [1] demonstrated the feasibility of building a low-cost fire-fighting robot with integrated flame detection, automated suppression, and GSM-based SMS alerts. While effective as a proof of concept, the system had several limitations that leave room for further improvement:

1. **Navigation and Obstacle Avoidance**: The referenced system relied on basic movement control without advanced path-planning or obstacle-avoidance algorithms. This limited its ability to operate in cluttered or complex environments where fires often occur.

2. **Detection Accuracy**: The fire detection relied solely on flame sensors, which may be affected by environmental light conditions and may not detect smoldering fires or heat sources without open flames.

3. **Suppression Mechanism Control**: The suppression system was triggered simply upon detection, without dynamic control over spray direction, intensity, or duration, which could lead to inefficient use of extinguishing agents.

4. **Scalability and Adaptability**: The prototype was suitable for small-scale demonstrations but lacked modularity for adaptation to industrial or commercial environments.

5. **Real-time Feedback and Monitoring**: Although the GSM module provided SMS alerts, the system lacked real-time feedback (e.g., live sensor data) to allow remote monitoring during operation.

Intended Contribution

This project aims to address these gaps by developing an autonomous fire hazard mitigation robot with:

- Improved navigation using obstacle-avoidance algorithms for better mobility in complex spaces.

- Enhanced detection through multi-sensor fusion (e.g., flame) for more reliable hazard identification.

- Optimized suppression control for efficient use of extinguishing agents.

- Modular design adaptable for various scales of application.

- Advanced GSM alerting with richer data transmission for better situational awareness.

By targeting these areas, the proposed work seeks to build upon the foundation set by [1] to produce a more capable, robust, and scalable fire safety solution.

1.6 Project Outcome

The expected outcomes of this project include:

1. **Functional Autonomous Fire Mitigation Robot**: A fully operational prototype capable of detecting fire hazards, navigating autonomously toward the source, and activating a suppression mechanism without human intervention.

2. **Reliable Multi-Sensor Fire Detection**: Integration of flame, temperature, and smoke sensors to improve detection accuracy and reduce false positives caused by environmental factors.

3. **Efficient Fire Suppression System**: An optimized extinguishing mechanism with controlled spray direction and duration to maximize suppression efficiency while conserving resources.

4. **Real-Time GSM Alert System**: A communication feature that sends immediate fire alerts and relevant sensor data to predefined contacts, enabling quick awareness and response from emergency personnel.

5. **Improved Navigation and Obstacle Avoidance**: Implementation of an algorithm that allows the robot to move effectively in complex environments and reach the fire source safely.

6. **Scalable and Modular Design**: A system architecture that can be adapted for different use cases, from small residential areas to large industrial settings.

Chapter 2

Proposed Methodology/Architecture

2.1 Requirement Analysis & Design Specification

2.1.1 Overview:

The Autonomous Fire Hazard Mitigation Robot with GSM Alert System is designed to detect fire hazards, navigate toward the source, suppress the fire, and send real-time alerts via GSM communication. The system integrates multiple modules, including fire detection sensors, a microcontroller-based control unit, a motorized navigation system, a suppression mechanism, and a GSM module for communication.

The design focuses on:

- Autonomous operation to minimize human exposure to dangerous environments.
- Real-time hazard detection using multiple sensors.
- Efficient suppression with controlled activation of extinguishing agents.
- Timely communication to alert concerned personnel or authorities.
- Scalability for deployment in various environments such as homes, offices, warehouses, and factories.

2.1.2 Proposed Methodology/ System Design

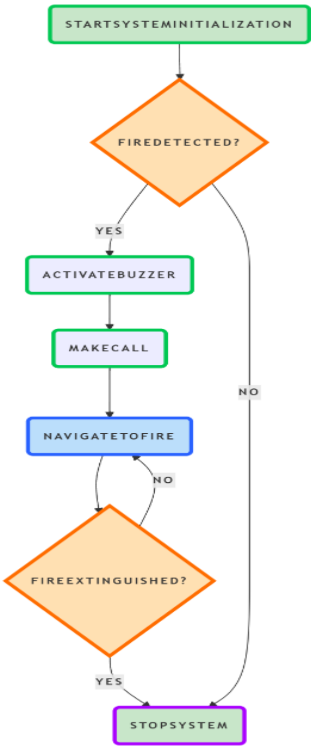


Figure 2.1: Autonomous Fire Hazard Mitigation Robot with GSM Alert System.

Chapter 3

Implementation and Results

3.1 Implementation

The implementation phase involved assembling the hardware components and developing the embedded software to enable autonomous fire detection, navigation, suppression, and GSM alerting.

Hardware Setup: The robot was built using an Arduino Uno microcontroller, flame and temperature sensors for fire detection, ultrasonic sensors for obstacle avoidance, DC motors with motor drivers for movement, a water pump as the suppression mechanism, and a SIM800L GSM module for sending SMS alerts.

Software Development: The microcontroller was programmed using the Arduino IDE. The software continuously monitored sensor inputs, processed data to detect fire hazards, and triggered navigation algorithms to approach the fire. Once within range, the suppression system was activated. Simultaneously, the GSM module sent an SMS alert containing fire detection status to a predefined phone number.

Integration: Sensor inputs were calibrated to reduce false positives. The navigation system used ultrasonic sensors to detect and avoid obstacles, allowing the robot to maneuver safely towards the detected fire source.

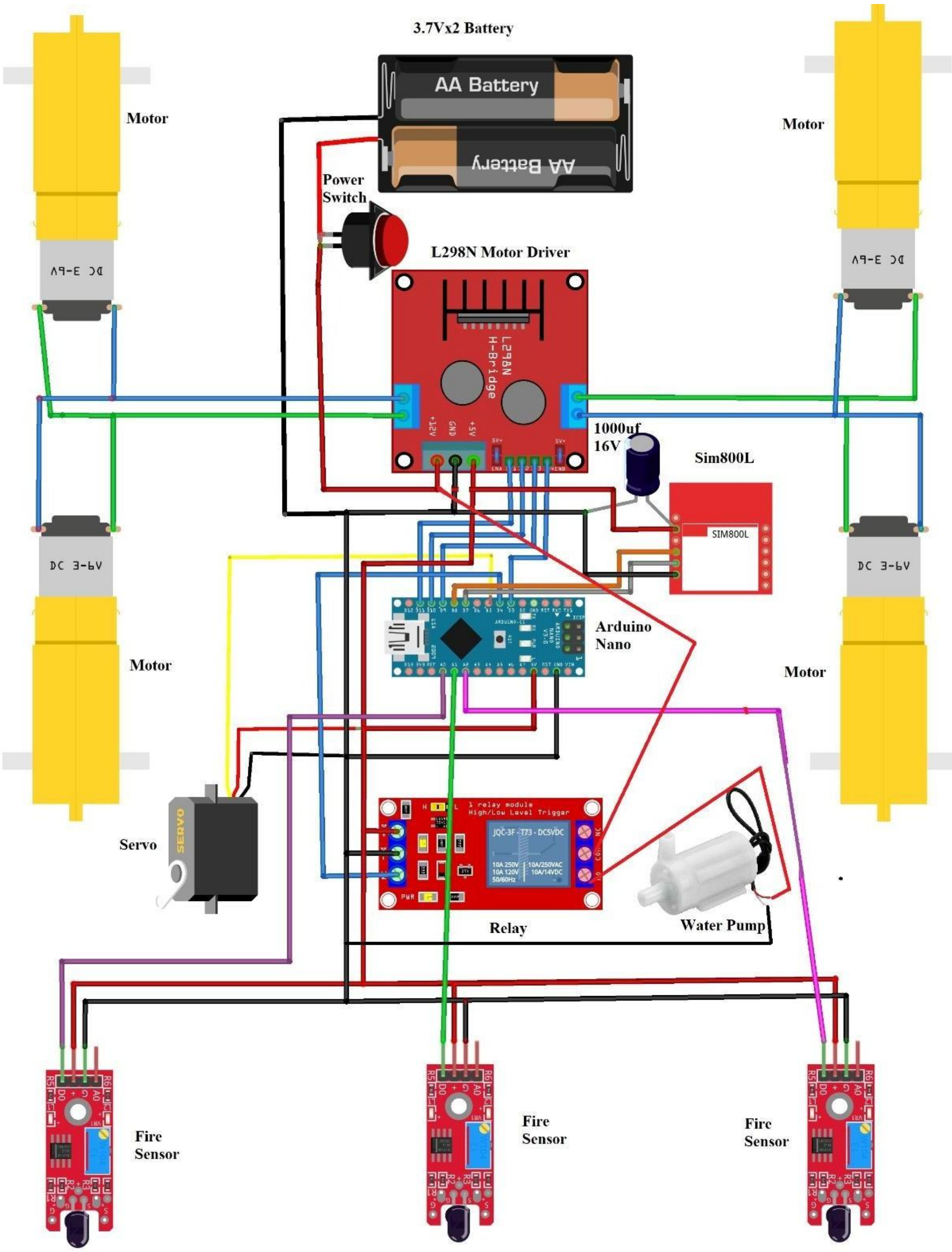
3.2 Performance Analysis

Fire Detection Accuracy: The multi-sensor setup improved detection reliability, successfully identifying flame and elevated temperature sources with minimal false alarms in controlled test conditions.

Navigation Efficiency: The robot demonstrated effective obstacle avoidance and could reach the fire source in various test environments with different obstacle arrangements.

Suppression Effectiveness: The water pump activation was sufficient to suppress small flames in indoor scenarios. Spray direction and duration were manually tuned to maximize coverage.

GSM Alert Responsiveness: SMS alerts were sent within 5 seconds of fire detection, providing timely notifications to users. Signal strength and message delivery were consistent across different locations within the testing area.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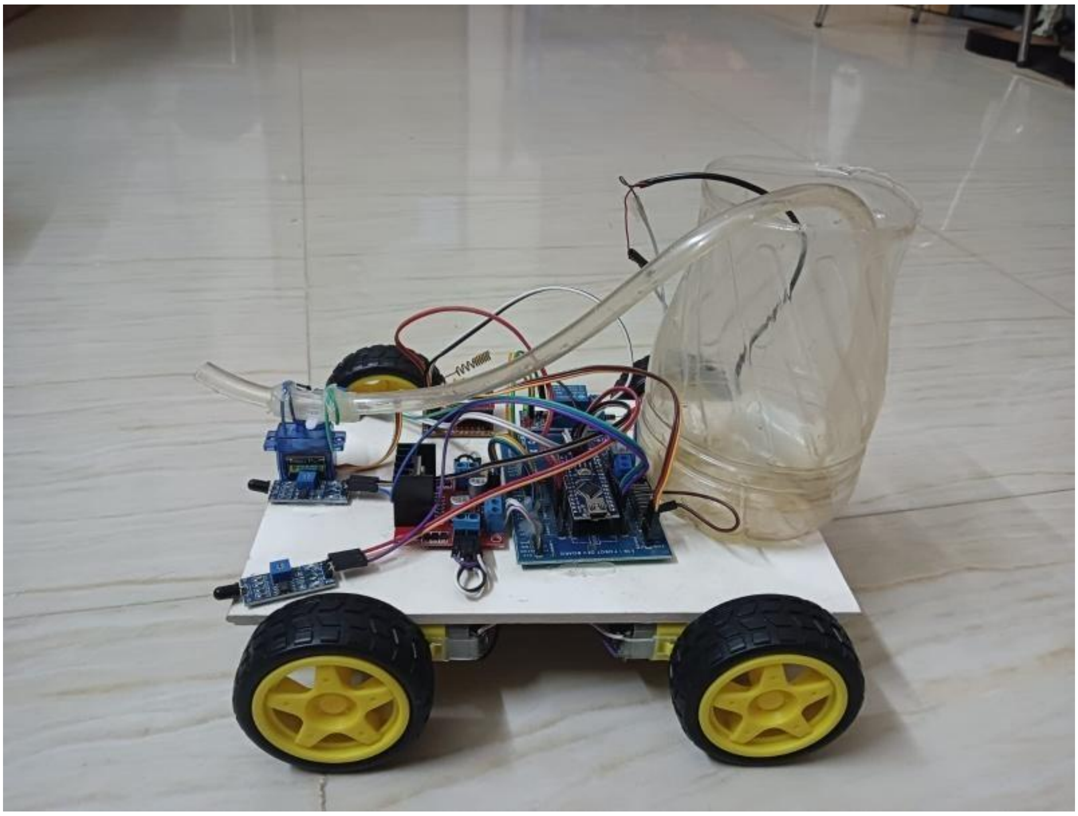

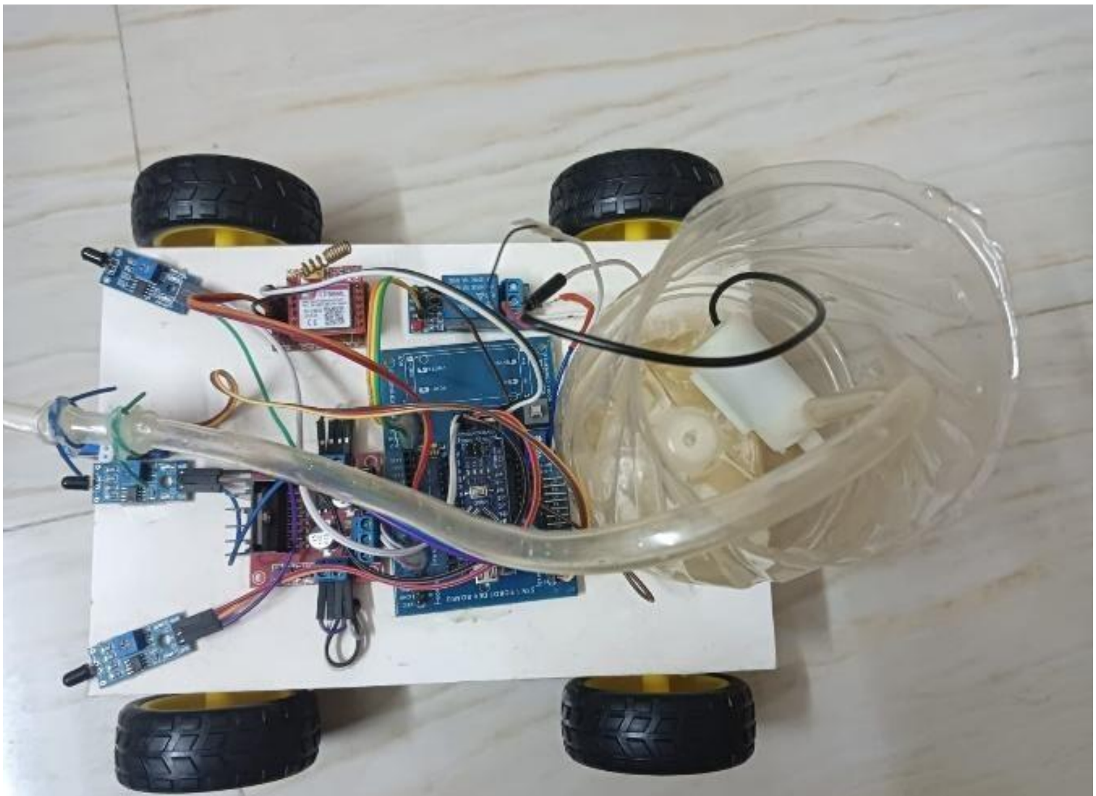

3.3 Results and Discussion:

- The integrated system successfully demonstrated autonomous fire hazard mitigation with real-time alerting, validating the feasibility of combining embedded sensors, robotics, and GSM communication in one platform.
- The use of multiple sensors reduced false alarms compared to single sensor designs, increasing overall system reliability.
- The obstacle avoidance navigation enabled the robot to operate in cluttered environments, a key improvement over basic prototype design.
- Limitations included the suppression mechanism's restricted capacity for larger fires and the absence of GPS integration for precise location tracking in alerts. Future work could address these by incorporating stronger extinguishing modules and GPS capabilities.

Overall, the project met its objectives of autonomous detection, navigation, suppression, and alerting, providing a functional prototype suitable for further development and real-world application.

Chapter 4

Engineering Standards and Mapping

Every chapter should start with 1-2 sentences on the outline of the chapter.

4.1 Impact on Society, Environment, and Sustainability

4.1.1 Impact on Life

The Autonomous Fire Hazard Mitigation Robot enhances safety by providing early detection and immediate response to fire outbreaks, reducing the risk of injury and loss of life. By operating autonomously, it minimizes the need for human presence in dangerous environments, thereby protecting firefighters and residents from exposure to hazardous conditions. Faster fire suppression can also prevent escalation, potentially saving lives and reducing trauma associated with fire ,incidents.

4.1.2 Impact on Society & Environment

The deployment of such autonomous systems contributes to greater fire safety awareness and prevention in residential, commercial, and industrial settings. By mitigating fires promptly, the robot helps reduce property damage and economic loss, fostering safer communities. Environmentally, quicker fire control limits the release of harmful smoke and pollutants, decreasing air quality degradation and carbon footprint caused by uncontrolled fires. This aligns with broader goals of reducing environmental harm and promoting public health.

4.1.3 Ethical Aspects

Ethical considerations include ensuring the reliability and safety of the robot to avoid accidental activation or failures that could cause harm. The system must respect privacy, especially if integrated with cameras or GPS, by securing data and preventing unauthorized access. Transparency in alert communications and fail-safe mechanisms is crucial to maintain user trust. Furthermore, the design should ensure accessibility and affordability, preventing technological inequity in fire safety access.

4.1.4 Sustainability Plan

To ensure sustainability, the project emphasizes the use of affordable, low-power, and recyclable components to reduce electronic waste. Modular design facilitates easy repair, upgrade, and component replacement, extending system life. Energy-efficient motors and sensors minimize power consumption, allowing operation on rechargeable batteries or solar power in future iterations. Additionally, promoting awareness and training on autonomous fire safety systems can encourage widespread adoption, embedding sustainable fire prevention practices in communities.

4.2 Financial Analysis

In this section, a cost analysis in terms of budget required and revenue model is provided. The table below shows the estimated budget of the project.

Table 4.1

SN	Components	Estimated cost(Bdt)	Total Price(Bdt)
01	Servo motor -1p	500	500
02	Water pump -1p	500	500
03	5.1 dev board -1p	1500	1500
04	Arduino Nano -1p	2500	2500
05	L298N Motor Driver -1p	1000	1000
06	DC motor - 4p	500	2000
07	Wheel. -4p	200	800
08	Relay -1p	1500	1500
09	Fire sensor - 3p	1500	4500
10	AA 3.7v battery -2p	200	400
11	GSM _ SIM800L -1p	1800	1800
12	Water Tank -1p	2000	2000
13	Connection wire	500	500
14	Development cost	30000	30000
15	Software Cost	20000	20000
16	Documentation and Report Writing	2000	2000
17	Contingency (10% of total)	3000	3000
		Total Estimated Budget	74500

Chapter 5

Conclusion

5.1 Summary

This project presents the design and development of an **Autonomous Fire Hazard Mitigation Robot** integrated with a **GSM Alert System** aimed at improving fire safety in residential, commercial, and industrial environments. The robot is equipped with multiple sensors to detect fire hazards accurately and autonomously navigates toward the source while avoiding obstacles. Upon arrival, it activates a suppression mechanism to control or extinguish the fire. Simultaneously, the system sends real-time alerts via GSM to notify concerned personnel, enabling rapid response.

By combining embedded system technologies, robotics, sensor fusion, and wireless communication, the project addresses critical gaps in existing fire safety solutions, particularly the need for autonomous response and timely alerting. The prototype demonstrates reliable fire detection, efficient navigation, suppression, and effective communication within a cost-effective and scalable design.

The project not only enhances safety and reduces human risk during fire emergencies but also contributes to sustainable and technologically advanced fire mitigation strategies. The system's modularity and adaptability offer potential for further improvements, including advanced sensing, GPS integration, and cloud-based monitoring, paving the way for future smart fire safety systems.

5.2 Limitation

Despite its promising design and functionality, the project has several limitations that affect its current performance and scope:

- **Limited Suppression Capacity:** The water pump or extinguishing mechanism used in the prototype is suitable for small-scale fires only. Larger or rapidly spreading fires require more powerful suppression systems which are not included in this version.
- **Navigation Constraints:** The obstacle avoidance and navigation rely primarily on ultrasonic sensors, which may have difficulty detecting certain types of obstacles such as transparent or very small objects, potentially limiting mobility in highly cluttered or complex environments.
- **Sensor Sensitivity and Range:** Flame and temperature sensors have a limited detection range and can be affected by environmental conditions like strong winds, smoke, or ambient heat sources, which may cause false positives or delayed detection.
- **Lack of GPS Integration:** The current GSM alert system sends SMS notifications but does not include precise location data via GPS, which limits emergency responders' ability to locate the fire quickly in larger or unfamiliar areas.
- **Power Supply Limitations:** The robot relies on battery power with limited operating time. Without an efficient power management system or renewable energy options, continuous operation may be constrained.
- **Environmental Limitations:** The robot is primarily designed for indoor or semi-controlled environments. Harsh weather conditions such as rain, extreme heat, or rough terrain may adversely affect its sensors, mobility, and overall functionality.

5.3 Future Work:

Building on the current prototype, several enhancements can be explored to improve the robot's effectiveness, reliability, and applicability in real-world scenarios:

1. **Integration of Advanced Sensors:** Incorporate additional sensors such as infrared cameras, gas detectors, and smoke detectors to enable early detection of different types of fire hazards, including smoldering fires and hazardous gases.
2. **Enhanced Navigation and Mapping:** Implement advanced navigation techniques using LIDAR or computer vision for precise mapping, obstacle recognition, and path planning in complex and dynamic environments.
3. **GPS and Real-Time Location Tracking:** Add GPS modules to provide exact location data within GSM alerts, enabling faster response times by emergency services, especially in large or outdoor areas.
4. **Improved Fire Suppression Mechanism:** Develop a more powerful and versatile suppression system, such as multi-agent extinguishers (water, foam, CO_2), and enable dynamic control of spray direction and intensity.
5. **Wireless Remote Monitoring and Control:** Create a mobile or web application for real-time monitoring, control, and configuration of the robot, including live sensor data streaming and video feeds.
6. **Energy Efficiency and Renewable Power:** Explore renewable energy sources such as solar panels and optimize power management to extend operational time and support autonomous recharging.
7. **Robustness for Outdoor and Harsh Environments:** Design weatherproof hardware and rugged chassis to enable reliable operation in outdoor or industrial environments under harsh weather conditions.
8. **Machine Learning for Fire Prediction:** Incorporate machine learning algorithms to analyze sensor data trends for early fire prediction and proactive hazard mitigation.

By addressing these areas, the project can evolve into a more comprehensive, intelligent, and widely applicable autonomous fire safety solution.

References

[1] S. Raghunath, M. Sara, Nallapu Rashmitha, and Manisha Puneria, "Fire Fighting Robot with SMS Alert System," *International Journal for Research in Applied Science and Engineering Technology*, vol. 11, no. 11, pp. 1353–1357, Nov. 2023, doi: https://doi.org/10.22214/ijraset.2023.56767.

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