RAMAIAH INSTITUTE OF TECHNOLOGY

(Autonomous Institute, Affiliated to VTU)

Project Report entitled

FIGHTING FIRES USING SWARM CONTROL ALGORITHM

Submitted in partial fulfilment for the award of degree of

BACHELOR OF ENGINEERING

in

Electronics and Communication

By

M S LALITHA RAMYA	**(1MS14EC051)**
MADALA VENKATA SIVA KRISHNA	**(1MS14EC054)**
MALLAPPA KOUJALAGI	**(1MS14EC055)**
NIDHI V	**(1MS14EC068)**

Under the Guidance of

Mrs. RESHMA VERMA
Assistant Professor, Department of E & C, RIT

Department of Electronics and Communication Engineering
RAMAIAH INSTITUTE OF TECHNOLOGY
(Autonomous Institute, Affiliated to VTU)
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MSR Nagar, MSRIT Post, Bangalore-560054

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Institute of Technology

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

CERTIFICATE

This is to certify that the project work titled **"FIGHTING FIRES USING SWARM CONTROL ALGORITHMS"** is carried out by **M S LALITHA RAMYA (USN-1MS14EC051), MADALA VENKATA SIVA KRISHNA (USN-1MS14EC054), MALLAPPA KOUJALAGI (USN-1MS14EC055)** and **NIDHI V (USN-1MS14EC068),** bonafide students of Ramaiah Institute of Technology, Bangalore, in partial fulfilment for the award of degree of Bachelor of Engineering in Electronics and Communication of Visvesvaraya Technological University, Belgaum, during the year 2017-18.

It is certified that all corrections / suggestions indicated for Internal Assessment have been incorporated in the report. The report has been approved as it satisfies the academic requirements in respect of project work prescribed for Bachelor of Engineering degree.

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Signature of Guide	Signature of HOD
Mrs. Reshma Verma Assistant Professor, Dept. of E&C, RIT.	Dr S. Sethu Selvi Professor and HOD, Dept. of E&C, RIT.

External viva:

	Name of Examiners	**Signature with date**
1.		
2.		

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

DECLARATION

We hereby declare that the final year project entitled "Fighting Fires Using Swarm Control Algorithms" has been carried out independently at Ramaiah Institute of Technology under the guidance of Mrs. Reshma Verma, Assistant Professor, Department of Electronics and Communication Engineering, RIT, Bangalore.

Signature of Students:

1. **M S Lalitha Ramya (USN: 1MS14EC051)**
2. **Madala Venkata Siva Krishna (USN: 1MS14EC054)**
3. **Mallappa Koujalagi (USN: 1MS14EC055)**
4. **Nidhi V (USN: 1MS14EC068)**

Place:

Date:

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Abstract

"Swarm" behaviour is displayed by many creatures in nature, that is, many single creatures coming together to create some emergent behaviour, based solely on simple actions taken by the individual members of the swarm.

There have been several suggestions for the purposes of swarming behaviour in different species. The most common of these is as a form of defence, with many proposals as to how the behaviour achieves this and other advantages of swarming have been observed, for example in discovery of food sources. Due to this obvious success in the observations, those involved in robotics have attempted to replicate natural examples to create "swarm intelligent" systems. The idea is that many small, cheap, disposable robots can work as one to achieve some goal by following simple behaviours.

Firefighting are executed mainly by human firefighters having to get very close to the actual fire, this presents many lethal risks from burns, smoke inhalations and other hazards. Also coupled with the loss of civilian life, loss of property is plenty especially with regard to fire caused by hazardous substances. Natural Swarm Systems which are a benchmark in efficiency and management can be used to implement system that can fight such fires.

The main intention of this project is to understand swarm control algorithms, develop a modified version of the same for cooperative firefighting and interface them with real robots to collectively fight fires.

This system is focused on using a swarm of robots to assist each other in extinguishing fire in areas such as industrial ware houses or highly inflammable areas like ammunition depots, fire crackers industries, petrochemicals industries and others.

Each individual robot plans its formation based on simple algorithm. When the robots are able to perform high level cooperative actions such as collaborative localization and coordinated navigation they will function as best they can in achieving the objective of fighting fires and can also provide assistance by giving the firefighter feedback from the robot's sensors for additional backup. They can also provide backup for other robots in the swarm should the need arise.

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Chapter 1 Introduction

1.1 Firefighting

For places such as industrial warehouses or department stores, fire is the ultimate nightmare. If a fire breaks out at night, when there's no-one around, and the building is stocked with furniture or flammable chemicals, the flames can spread in no time. Even if fire claims no lives, it can still be devastating: loss of stock or the building itself. It makes sense to have a fire-fighting system that can react the moment fire strikes. This system should not just sound an alarm but should also automatically extinguish the fire as quickly as possible.

Installation of Automatic Fire Suppression Sprinkler System also known as Fire Sprinkler System is one of the solutions being adopted at the present. These are valves used to control the flow of water. They operate as valves by allowing the flow of water contained in a fire sprinkler system when the heat sensitive element (glass bulb or fusible link) is operated. This is caused when the fire sprinklers are exposed for a sufficient time to a temperature at or above the temperature rating of the heat sensitive element.

Fire caused by gas leak and chemical oil could cause an explosion, so dangerous to human life and we would ideally like to move humans away from this situation. Though the human fire-fighters are trained to handle various situations, it involves them having to get very close to the actual fire which presents many lethal risks from burns, smoke inhalations and other hazards. Additionally, variation in temperature level and heat generated from the fire is beyond the capabilities of the humans to senses and react to immediately.

Technological advancements have led to devising a more efficient solution by using robot technology embedded with various algorithms to help achieve the required goals. One such example is the fire-fighting robots that are specifically designed to help humans, especially for firemen to extinguish fire. For this purpose, sensors can be placed in the external environment (warehouse) as well as internally within the robots and effective action at the correct location of the fire can be accomplished instantly by the robot systems even at high temperatures leading to minimal property loss.

Several swarm control algorithms can be implemented based on the needs of the system for its efficient operation. In this case, swarming would be used to control a cheap swarm of robots capable of firefighting. This system is focused on combining robot technology and swarm algorithms to develop a swarm of robots to assist in dousing the fires primarily in industrial warehouses. When the robots are able to perform high level cooperation such as collaborative localization and coordinated navigation, they will, but otherwise they will function as best they can independently. There is negligible human interference in the operation of such a system, facilitating an autonomous system as a whole.

1.2 Swarm Intelligence

Swarm intelligence (SI), as observed in natural swarms, is a result of actions that individuals in the swarm perform exploiting local information, which is communicated, indirectly through the environment, by their neighbours.

There are a multitude of examples of such behaviour, for example schools of fish, flocks of starlings and colonies of ants. In all of these examples the sole actors in the swarm make their own decisions based on their environment and the behaviour of those around them, resulting in advantages to the group as a whole. There have been several suggestions for the purposes of swarming behaviour in different species. The most common of these is as a form of defence, with many proposals as to how the behaviour achieves this.

One example of this phenomenon that is well established and extensively studied is the group foraging by ants: An ant lays a chemical called pheromone on its way during its search for food, thus forming a pheromone trail; when a food source is found, it returns back to the nest, while simultaneously reinforcing the retraced trail with more pheromone. However, when another ant randomly searching for food encounters a pheromone trail by chance, it starts to follow the pheromone trail, with a high probability, the trail with the high pheromone level; eventually, it reached either the food source or the nest. As the pheromone decays with time, pheromone trails that are circuitous and less visited by ants may be quickly lost in the due course of time; however shorted routes between the food source and the nest maybe positively reinforced frequently enough before they are lost. This process eventually results in the emergence of a shortest route between the nest and the food source.

Based on the example, one such proposed way to control the swarms is Ant Colony Optimization (ACO). In this case the robots (or ants) are positioned at starting points, with each iteration they will sense the pheromone levels of their neighbours and determines its next action based on that. The aim of this pheromone laying in this case is to find the shortest path possible from the fire to the nest to allow robots to go back and forth as quickly as possible; either to the fire or to the “nest” to refill its water tanks. This is done by laying pheromone values, the values closet to the goal (i.e., the fire front) will have the highest values, and the robots will be encouraged to choose from a series of these high points. A randomness factor is added in order to diversify the search and to avoid robots covering a single path.

It can be seen in the above example how ants use pheromone trails collectively to exhibit swarm behaviour. However, the method of communication and/or the purpose of swarming differs from one species to another. For instance, honeybees use waggle dances performed by other honeybees as cues to find the direction and distance to food sites. Glow-worms exploit the property of bioluminescence in a variety of ways for the purpose of mating and species preservation and the algorithm based on Glow-worm Swarm Optimization can be utilized in the similar manner as that of ACO for fighting fires with an increased efficiency in the functioning of the robots to instantly douse fires.

Furthermore, in nature one of the most important factors in a species’ ability to swarm is some form of communication to influence the swarms behaviour as a whole. There appear to be three main types of communication that appear in the natural world. Firstly, communication by copying other creatures’ behaviour in the swarm and altering your own actions based on them. It is understood that each creature will survey the distance, perceived speed and direction of movement of its neighbours in order to decide on its own movements. this is the technique employed by both bird flocks and schools of fish. Secondly some creatures directly communicate via signals of some kind (such as sounds or body movements), for examples bees signal each other in this manner when coming to decisions on where the swarm should go, and to inform the rest of the swarm of food sources. Finally, implicit communication such as ants laying pheromone trails. This implicit communication is known as stigmergy, strictly, communicating via signals left in the environment. Of course, there is a huge variation in nature and many novel communication techniques exist to allow animals to communicate and form swarms.

Communication in robot swarm systems is, of course, equally important. In order to achieve a useful global behaviour the robots must follow certain rules, usually based on the global and relative positions of the robots, and state of their companions, which is similar to some of the examples from nature. Along with this information the robots take into account other factors such as their predetermined objectives in order to decide upon their actions. This means the robots must have some form of communication channel to relay this information to each other in an ad-hoc fashion; usually via a combination of technologies such as

Bluetooth or ‘Wi-Fi’. Along with these communication devices, the robots also tend make use of some or all of the following: GPS for positioning, accelerometers and/or compasses for directional information, cameras and other sensors to recognise the environment.

Along with communication, coordination and cooperation are very important for swarm robotic systems and much research has been put into the best way to achieve this. To create a useful emergent behaviour in a system, where robots are dependent on each other’s performance, co-ordination of robots is key, creating a consensus on the current goals and how the robots should act together to complete them.

The swarm mechanisms hence offer an insight into basis to devise decentralized decision-making algorithms that solve complex problems related to diverse fields such as optimization, multi-agent decision-making and collective robotics.

1.3 Glow-Worm Swarm Optimization (GSO)

GSO is originally developed for numerical optimization problems that involve computing multiple optima of multimodal functions, as against other swarm intelligence algorithms which aim to identify the global optimum. The algorithm also prescribes decentralized decision-making and movement protocols useful for swarm robotics applications.

For instance, a robot swarm can use GSO to carry out disaster response tasks comprising search for multiple unknown signal sources; examples of such sources include nuclear spills, hazardous chemical spills, leaks in pressurized systems and fire-origins in forest fires. It has been recognized that GSO’s approach of explicitly addressing the issue of partitioning a swarm required by multiple source localization is very effective.

GSO is based on the behaviour of glow worms. The behaviour pattern of glow worms which is used for this algorithm is their apparent capability to change the intensity of bioluminescence and thus appear to glow at different intensities. Each glow worm or agent in GSO is assumed to carry a luminous pigment called luciferin, whose quantity encodes the fitness of its location in the objective space. This allows the agent to glow at an intensity approximately proportional to the function value being optimized. It is assumed that agents glowing with brighter intensities attract those glowing with lower intensity. In particular, each glow worm selects, using a probabilistic mechanism, a neighbour that has a luciferin value higher than its own and moves towards it. The algorithm incorporates an adaptive neighbourhood range by which the effect of distant glow worms is discounted when a glow worm has sufficient number of neighbours or the range goes beyond their maximum range of perception. These movements based only on local information and selective neighbour interactions enable the swarm of glow worms to split into disjoint subgroups that converge to high function value points. This property of the algorithm allows it to be used to identify multiple optima of a multimodal function.

Natural glow worms perform individual courtships by using the bioluminescent light to signal, and taxis toward, other individuals of the same species. In the case of mass mating, they initially gather to form a few nuclei by mutual photic attraction. Later, these nuclei of glow worms act as bright beacons to attract others from far away distances, eventually forming large congregations. In these congregations, centres of higher mean intensity outdraw nearby ones of lower mean intensity. The general idea in GSO is similar in the following two aspects:

- Agents are assumed to be attracted to move toward other agent that have higher luciferin value (brighter luminescence).
- The multiple peaks can be likened to the nuclei of glow worms, formed during the beginning of the mass mating process, that serve as bright beacons.

1.3.1 Multimodal Function Optimization

The traditional class of problems related to this topic focused on developing algorithms to find either one or all the global optima of the given multimodal function, while avoiding local optima. However, there is another class of optimization problems, which is different from the problem of finding only the global optima. The objective of the latter class is to find multiple local optima. The knowledge of multiple local and global optima has several advantages such as obtaining an insight into the function landscape and selecting an alternative solution when the dynamic nature of constraints in the search space makes a pervious optimum solution infeasible to implement.

1.3.2 Multiple Source Localisation

Localization of signal sources using mobile robot swarms has received some attention recently in the collective robotics community. Examples of such signal sources include sound, heat, light, leaks in pressurized systems, hazardous plumes/aerosols resulting from nuclear/chemical spills, fire origins in forest fires, deep sea hydrothermal vent plumes, hazardous chemical discharge in water bodies, oil spills, etc. The problem is compounded when there are multiple sources. For instance, several forest fires at different locations give rise to a temperature profile that peaks at the location of the fire. Similar phenomenon can be observed in nuclear radiations and electromagnetic radiations from signal sources. In all the above situations, there is an imperative need to simultaneously identify and neutralize all the sources using a swarm of robots before they cause a great loss to environment and people in the vicinity.

Based on the nature of the emission source and the ambient medium, the source localization problem can be broadly classified into two categories:

- Signals such as sound, light and other electromagnetic radiations propagate in the form of a wave. Therefore, the nominal source profile that spreads in the environment can be represented as a multimodal function and hence, the problem of localizing their respective origins can be modelled as optimization for multimodal functions.
- Chemical signals that are emitted by sources such as hazardous chemical aerosols, gas leaks, etc., disperse through the environment by molecular diffusion and bulk flow. The chemical source gradually dissolves into the ambient fluid medium resulting in odour plumes. A plume can be defined as those regions of space that contain the set of all molecules released from a single source. Turbulence I the flow of ambient fluid renders the plume discontinuous and patchy where patches of ambient fluid are interposed between patches of odour. Owing to reasons mentioned above, the source profile in these cases cannot be modelled using a static multimodal function and should be represented using dynamic gas model that account for factors like diffusion and turbulence.

The basic GSO algorithm is suited to the first category of source localization problems, in which the assumption of using a multimodal function to represent the nominal source profile is justified. Therefore, GSO is applied to the first category of problems.

While the application of evolutionary approaches is largely limited to numerical (discrete combinatorial or continuous) optimization problems that involve computer based experiments, the particle nature of individuals in swarm based optimization algorithms enable their application to realistic collective robotics tasks, with some modifications where necessary. Swarm robotics is increasingly being used for source detection applications. Other approaches to robotic signal source localization include occupancy grid based, gradient based and model based strategies.

1.3.3 GSO for Multi-Agent Rendezvous

Consensus problems in multi-agent networks, in particular, robotic networks, appear in various forms, where several agents transit from an initially random state to a final steady state in which all the members of the group agree upon their individual state values. The agent's state could represent physical quantities such as heading angle, position, frequency of oscillation and so on.

GSO prescribes agent protocols to solve a closely related problem in which the rendezvous locations are assigned to multiple signal centres that are unknown a priori.

Chapter 2 Background and Problem Statement

2.1 Firefighting Systems for Indoor Environments

National Fire Protection Association has issued statistics on the number of firemen at the normal age suffering from line-duty deaths are due to heart attack by 25 percent, 21 percent die trapped by fire, 18 percent died after falling from a high place and the rest suffer from cancer as a result of direct contact with chemicals and poisonous. Firemen are more vulnerable to death in the course of their daily routine firefighting. The use of robots is one of the alternative medium for reducing firemen casualties and enhancing fire extinguishing system's capabilities.

Small fires from short circuits, gas stoves or other factors in the residence cannot be detected by human's sensitivity while robot design equipped with high sensitivity sensors can detect the presence of heat, smoke and fire. Unlike humans, the robots have maximum capacity as they are alert, do not get exhausted and are able to perform spontaneously and at any given time based on the task embedded into the robots.

The time factor is a problem in a fire situation. A small fire takes just a few minutes before they spread out on a wide scale. Information through a phone call about a fire that was reported to firemen need time to determine the location of fire. The information of burning location must be recorded before the firemen go to that place. Moreover, the vehicle they are driving, large and difficult to pass through the traffic jam. Through the development of firefighting robot, the time can be reduced by placing the robot in a high-risk area of a fire.

2.1.1 Sprinkler Systems

Sprinkler systems are intended to either control the fire or to suppress the fire. Control mode sprinklers are intended to control the heat release rate of the fire to prevent building structure collapse, and pre-wet the surrounding combustibles to prevent fire spread. The fire is not extinguished until the burning combustibles are exhausted or manual extinguishment is affected by firefighters.

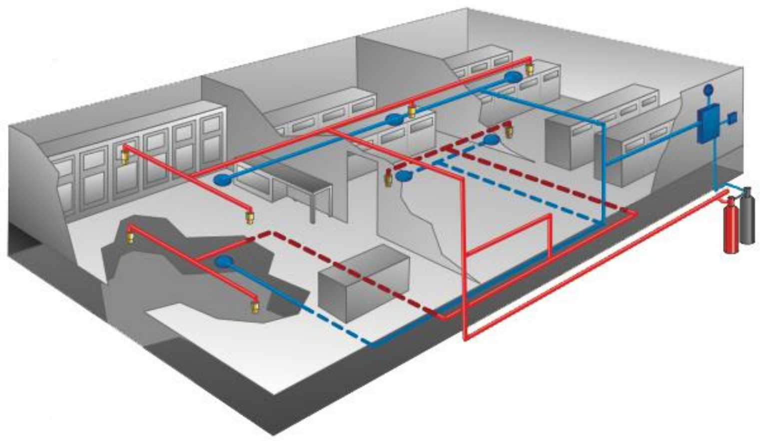

Figure 2.1 Fire Suppression Sprinkler System in Warehouses

2.1.2 Sprinkler Colour Codes

A key part of any sprinkler system is the bulb. The bulb can vary in thickness. Colours vary according to temperature settings, as detailed in the table below.

Table 2.1 Relation between Glass Bulb Colour Code to Temperature

Temperature		**Colour of Liquid Alcohol inside Bulb**
°C	**°F**	
57	135	Orange
68	155	Red
79	174	Yellow
93	200	Green
141	286	Blue
182	360	Purple
227 or 260	440 or 500	Black

Ordinary sprinkler systems have orange or red bulbs. Intermediate, yellow or green. High temperature bulbs are coloured in blue up to 246 degrees Celsius, then purple up to 302 degrees Celsius, and black for anything above. These fall in the Very Extra High and Ultra High categories. The Figure in the next page shows the relationship with temperature

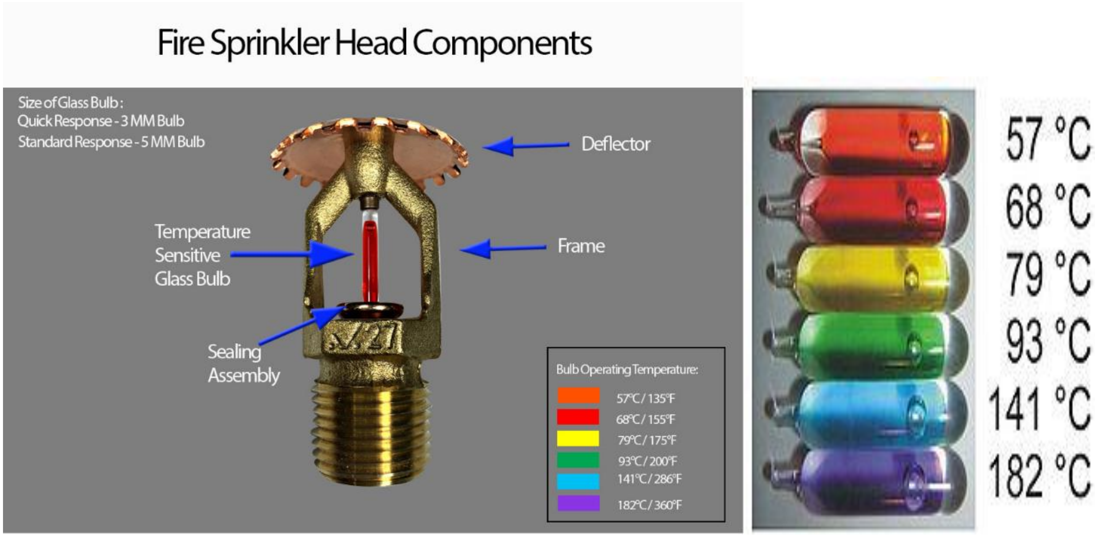

Figure 2.2 Structure of a Fire Sprinkler and Colour Bulbs

2.1.3 Operation

Each closed-head sprinkler is held closed by either a heat-sensitive glass bulb or a two-part metal link held together with a fusible alloy such as Wood's metal and other alloys with similar composition. The glass bulb or link applies pressure to a pipe cap which acts as a plug which prevents water from flowing until the ambient temperature around the sprinkler reaches the design activation temperature of the individual sprinkler.

The bulb breaks as a result of the thermal expansion of the liquid inside the bulb. The time it takes before a bulb breaks is dependent on the temperature. Below the design temperature, it does not break, and above the design temperature, it breaks, taking less time to break as temperature increases above the design threshold. The sensitivity of a sprinkler can be negatively affected if the thermal element has been painted.

2.1.4 Problems of Fire Suppression Sprinkler Systems

- Installation – Most sprinkler systems installed today are designed using an area and density approach. The design area is a theoretical area of the building representing the worst-case area where a fire could burn. The design density is a measurement of how much water per square foot of floor area should be applied to the design area. After the design area and density have been determined, calculations are performed to prove that the system can deliver the required amount of water over the required design area. These calculations account for all of the pressure that is lost or gained between the water supply source and the sprinklers that would operate in the design area. This includes pressure losses due to friction inside the piping and losses or gains due to elevation differences between the source and the discharging sprinklers. Sometimes momentum pressure from water velocity inside the piping is also calculated. Typically, these calculations are performed using computer software or sometimes complicated calculations were performed by hand. This skill of calculating sprinkler systems by hand still requires training for a sprinkler system design technologist.

- Dampening problem – Damage due to water is of concern. One of the methods used in sprinkler systems is to pre-wet the surrounding combustibles to prevent fire spread. Furthermore, when a fire does break out, the sprinklers get activated and the area over which the water spreads is neither restricted nor can be accurately controlled which leads to damage due to unnecessary dampening of other goods that are not in the near vicinity of the fire.
- Cost factor – Sprinkler systems need to be installed with care considering the distribution of location of the items within the warehouse. It also involves continuous maintenance to ensure proper functioning. These factors contribute to initial as well as other expenses increasing the overall cost of the system.
- Water Pressure – If the sprinklers share the same standpipe system as the standpipe system which supplies fire hoses, then the water supply to the fire hoses would be severely reduced or even curtailed altogether.
- Increased complexity – This is because we have to maintain the pressure of water in the system. This puts a premium on proper maintenance, as this increase in system complexity results in an inherently less reliable overall system.
- Lower design flexibility – Regulatory requirements limit the maximum permitted size, unless additional components and design efforts are provided to limit the time from sprinkler activation to water discharge to under one

minute. These limitations may increase the number of individual sprinkler zones (i.e. served from a single riser) that must be provided in the building, and impact the ability of an owner to make system additions.

- Increased fire response time – Because the piping is empty at the time the sprinkler operates, there is an inherent time delay in delivering water to the sprinklers which have operated while the water travels from the riser to the sprinkler, partially filling the piping in the process. A maximum of 60 seconds is normally allowed by regulatory requirements from the time a single sprinkler opens until water is discharged onto the fire. This delay in fire suppression results in a larger fire prior to control, increasing property damage.
- Increased corrosion potential – Following operation or testing, fire sprinkler system piping is drained, but residual water collects in piping low spots, and moisture is also retained in the atmosphere within the piping. This moisture, coupled with the oxygen available in the compressed air in the piping, increases internal pipe corrosion, eventually leading to pin-hole leaks or other piping failures. Corrosion can be combated using copper or stainless-steel pipe which is less susceptible to corrosion, or by using dry nitrogen gas to pressurize the system, rather than air. These additional precautions can increase the up-front cost of the system, but will help prevent system failure, increased maintenance costs, and premature need for system replacement in the future

2.1.5 Solution

Studies and observations made in the field of robotics and swarm algorithms have given us an idea to help overcome the problems caused due to the sprinkler system, by using swarming techniques which can be utilized to control a cheap swarm of robots capable of fire-fighting/fire-dousing techniques.

2.2 Literature Survey

2.2.1 Technical Report: Swarm Intelligence: Concepts, Models and Applications, Authors: Hazem Ahmed, Janice Glasgow, School of Computing, Queen's University, Kingston, Ontario, Canada [1]

Concepts understood and utilized:

- Introduction to Swarm Intelligence and the various computational models inspired by natural swarm systems; A swarm is a large number of homogenous, simple agents interacting locally among themselves, and their environment. Swarm Intelligence (SI) can therefore be defined as a relatively new branch of Artificial Intelligence that is used to model the collective behaviour of social swarms. These are relatively unsophisticated with limited capabilities on their own, they interact together with certain behavioural patterns to cooperatively achieve tasks necessary for their survival.
- Advantages of Swarm Intelligence based Systems, types and comparison amongst various systems which include Ant Colony Optimization (ACO) Model, Particle Swarm Optimization (PSO) Model, Artificial Bee Colony, Bacterial Foraging, Cat Swarm Optimization, Artificial Immune System and Glow-worm Swarm Optimization and their applications.

2.2.2 Paper 1: Ants Based Control of Swarm Robots for Bushfire Fighting, Authors: D. Wang, N.M. Kwok, G. Fang, Xiuping Jia, F. Li, School of Engineering & Information Technology, University of New South Wales, Sydney, NSW, Australia [2]

Concepts understood and utilized:

- Understanding the Metaheuristics and how Ant Colony Optimization algorithm can be used for controlling swarms of fire-fighting robots.
- Advantages of using centralised processing in the swarm and identifying the various problems that can occur during the implementation which shows that the environment is constant as the map is already supplied to the algorithm but in our system the environment can keep changing.

Additionally, the intensity of the fire is constant but our system can adapt and dynamically change the number of robots required per fire based on the intensity of the fire.

2.2.3 Paper 2: Guardians Robot Swarm Exploration and Firefighter Assistance, Authors: Ali Marjovi, Lino Marques, Jacques Penders, Institute of Systems and Robotics, University of Coimbra, Portugal, Sheffield Hallam University, Sheffield, UK [3]

Concepts understood and utilized:

- Different methods by which we can overcome problems of localization as GPS does not provide good accuracy in indoor environments. Multiple sensor fusion, approximation methods and various forms of data communication within the swarm (distributed processing), between the swarm and the central control system including their respective merits and demerits.
- In multi sensor fusion we can use SLAM for each and every robot along with other wide variety sensors but the computational requirements and data flow within the system is higher which defeats the entire purpose of Swarm Intelligence, i.e., Robust, Adaptable, Flexibility. In approximation methods we just determine the approximate position of the robot using simple calculation such as knowing the distance travelled and the direction of motion of the robot.
- In this system the robot automatically follows the fire-fighter but doesn’t go to the fire automatically. It can also be controlled by the fire-fighter using a helmet mounted interface.

2.2.4 Paper 3: Swarm Intelligence for Autonomous UAV Control, Author: Natalie R Frantz, Naval Postgraduate School, Monterey, California [4]

Concepts understood and utilized:

- Comparison of the PSO algorithm and the backpropagation algorithm and comparison of PSO and the Linear Control method used. Describes a linear control approach to organizing a swarm of UAVs.

- The main problem we have seen is that in the aerial domain there are no obstacles. We can consider birds to be obstacles but general flight paths are taken in accordance to not disturb the migratory pattern of the migratory birds and also for air currents that are in favour of the direction of travel for fuel efficiency. But in terms of War scenario all these are not considered as most UAV's don't use jet engines due bird ingestion. So, this is highly improbable scenario.

2.2.5 Textbook Reference: Glow-worm Swarm Optimization-Theory, Algorithms, and Applications, Authors: K.N. Kaipa, D. Ghose [5]

Concepts understood and utilized:

- The glow-worm swarm optimization (GSO) algorithm, including details of the underlying ideas, theoretical foundations, algorithm development, various applications, and MATLAB example programs for the basic GSO algorithm.

2.3 Proposed Idea

From the above research of already existing material, we concluded that the generality of the GSO algorithm is evident in its application to diverse problems ranging from optimization to robotics and this algorithm is the best solution to the system we want to implement.

We have hence decided to use the robot technology combined with the GSO algorithm to help in the dousing of fires in warehouses using terrain based robots for efficient and quick response.

2.3.1 Project Objectives

- To demonstrate that Swarm Control Algorithms can be used for Firefighting.
- Build two-three prototypes of Robots
- Code the required Algorithm for implementing Swarm functionality and communication between the Robots.
- Build and implement Fire Extinguishing methodology.

- Simulate the above system in various scenarios to understand the performance of the algorithm and make required adjustments to enable them to adapt to their surroundings.

2.3.2 Intended Characteristics of the System

Considering the various concepts that we understood from the research papers and documents, we observe that there are three primary reasons that justify the interest in creating swarm intelligent systems.

- **Robustness**, the ability to continue the completion of a task (although at reduced capacity) despite the loss of an individual in the swarm.
- **Flexibility**, allowing a modular approach to achieve different tasks based on changes in the environment, in our case, call multiple robots to put out larger fires.
- **Scalability**, the addition of new robots to the swarm should be seamless and allow the swarm to increase capacity without extra configuration, meaning a system can grow as and when it needs to with little or no human intervention.
- **Superior Performance,** when compared to already existing Firefighting techniques.

The concept is based on controlling vast numbers of minuscule robots simultaneously, with the objective of carrying out a task that would be too complex for a single machine to accomplish.

The main functions of the fire-fighting robot include

- Detection of fire
- Obstacle Avoidance and Dynamic Mapping of Environment
- Extinguishing Fire

Chapter 3 Methodology

3.1 Overview

The development of a swarm of robots for firefighting along with the control algorithm has two main design considerations to be taken into account namely the

- Design, Functionality and Communication Interface of the Robot.
- Control algorithm for the swarm derived from Glow-worm Swarm Optimization.

The main assumptions of the environment and our system in which the tests have been carried out:

- Fire already exists in the environment after every iteration.
- A Robot can only move in 4 directions (forward, backward, left, right).
- The distance that a robot moves after every single movement command is 0.4m.
- The area of the warehouse under consideration is of size 4m x 4m.
- Due to the above 2 assumptions the entire warehouse is divided in blocks of 0.4m x 0.4m and are given grid numbers as shown in fig 3.1.
- The number of fire locations should be less than or equal to the number of robots in the system.

1	11	21	31	41	51	61	71	81	91
2	12	22	32	42	52	62	72	82	92
3	13	23	33	43	53	63	73	83	93
4	14	24	34	44	54	64	74	84	94
5	15	25	35	45	55	65	75	85	95
6	16	26	36	46	56	66	76	86	96
7	17	27	37	47	57	67	77	87	97
8	18	28	38	48	58	68	78	88	98
9	19	29	39	49	59	69	79	89	99
10	20	30	40	50	60	70	80	90	100

Figure 3.1 Map of the Indoor Environment

The fire location data is given to the central system which then plans the path for the respective robots and starts sending movement commands to those robots through Wi-Fi. Once the robots reach their respective fire location they extinguish the fire. After extinguishing the fire, the robots move back to their initial position. While moving the robot also keeps a track of the environment using the ultrasonic sensors to detect any dynamic obstacles. We are creating a swarm consisting of 3 robots and the area of the environment in which we are simulating and running our system is 4m x 4m. Also our robot can only move in 4 directions (forward, backward, left, right). The distance that a robot moves after every single movement command is 0.4m.

3.2 Proposed Method

The method proposed is that the swarm of robots will receive movement commands from the Central Server while the robots send back environment data, fire sensing data when requested by the Central Server. The Central Server holds the Control Algorithm which has complete situational awareness and can automatically take routing decisions for the robots based on the changes in the environment. The proposed system is shown in fig 3.2

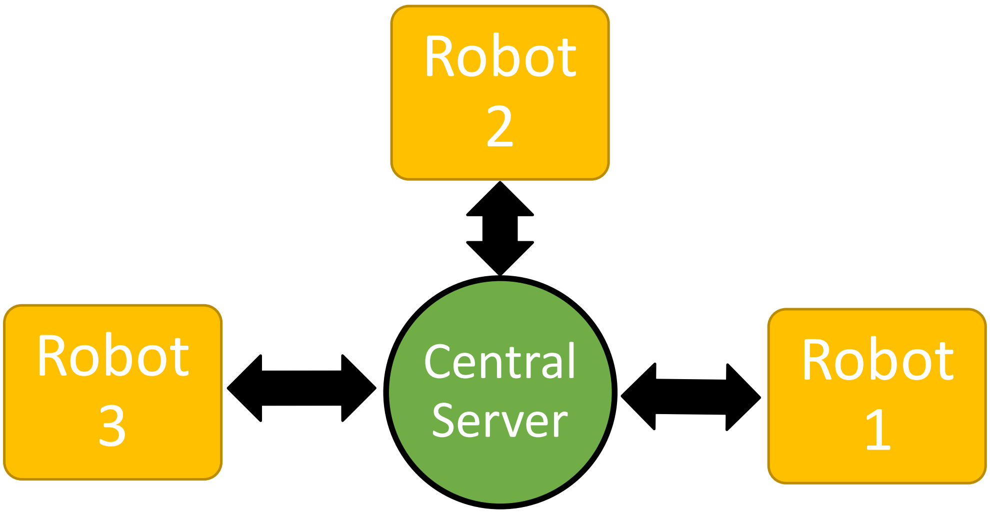

Figure 3.2 Flowchart of the Proposed Swarm System

3.2.1 Advantages of the proposed method

- Scalability – The ability to add robots to the system without the need for any fundamental changes
- Robustness – The ability to operate the system efficiently even when some of the robots are offline.

- Ability of the system to fight fires over a broad range of temperature without any changes to the configuration.
- Ability of the system to fight fire in multiple locations.
- Fast Response Time of the System when compared to conventional methods.
- Targeted Fire Fighting Ability instead of Scorched Earth approach.
- Swarm-based algorithms have recently emerged as a family of nature-inspired, population-based algorithms that are capable of producing low cost, fast, and robust solutions to several complex problems.
- No human intervention is necessary.
- If required in dire situations, they can also provide assistance by giving the firefighter feedback from the robot's sensors for additional backup.

3.3 Design, Functionality and Communication Interface of the Robot

The Robot consists of an Arduino Mega 2560 microcontroller which uses a NodeMCU as a Wi-Fi shield to connect to the Wi-Fi Network. The Fire Sensing function of the Robot is done by the Flame Sensor place in front of the Robot. The Obstacle Detection function of the Robot is done by Ultrasonic Sensors placed in the front, left, right of the Robot. The Motors are controlled using a L293D Motor Driver. The Robot has to make perfect 90 degree turns and this is ensured by a turn control system consisting of Magnetometer and Servo meter is used. The Structure of the Robot is shown below in the fig 3.1

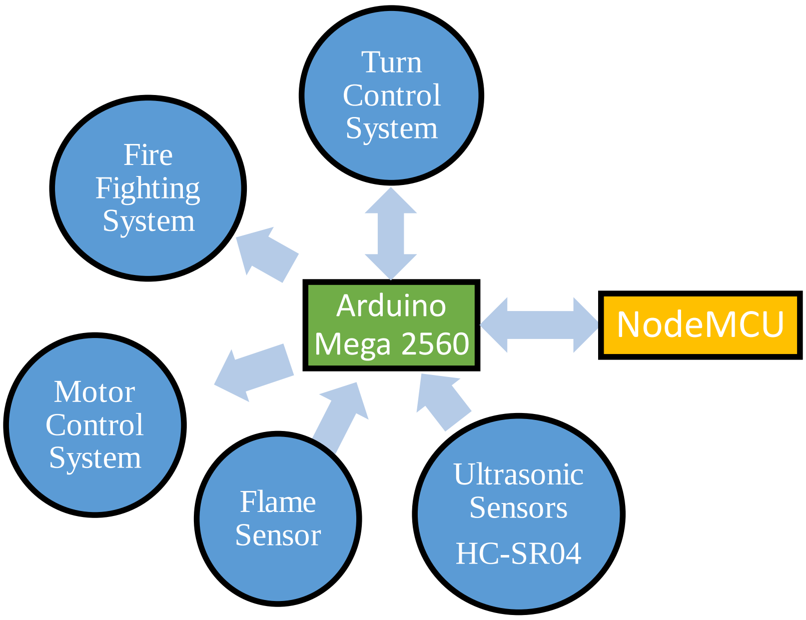

Figure 3.3 Structure of the Robot

3.3.1 Flame Sensor

The Flame Sensor module has a Built in a potentiometer for sensitivity control. It has 2 On-board LED's green one for flame detection and red one for power. The Output Signal can be directly connected to Arduino Mega 2560 Digital or Analog pins. It can detect a flame in a range of 760 - 1100 nm wavelength of the light at a distance of 80cm. The detection angle of the sensor is 60 degrees. The sensitivity of the sensor can be adjusted by varying the potentiometer.

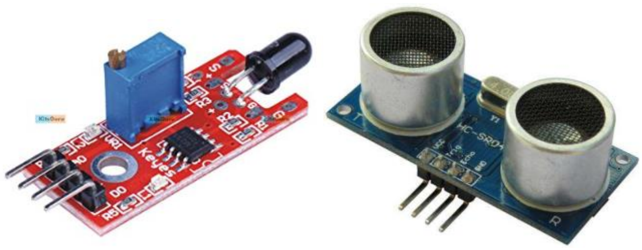

Figure 3.4 Flame Sensor(left) and HC-SR04 Ultrasonic Sensor(right)

3.3.2 Ultrasonic Sensor

HC-SR04 is an ultrasonic ranging module that provides 2 cm to 400 cm non-contact measurement function. The ranging accuracy can reach to 3mm and effectual angle is < 60°. It emits an ultrasound at 40 000 Hz which travels through the air and if there is an object or obstacle on its path It will bounce back to the module. Considering the travel time and the speed of the sound you can calculate the distance. The HC-SR04 Ultrasonic Module has 4 pins, Ground, VCC, Trig and Echo. The Ground and the VCC pins of the module needs to be connected to the Ground and the 5 volts pins on the Arduino Board respectively and the trig and echo pins to any Digital I/O pin on the Arduino Board. In order to generate the ultrasound, you need to set the Trig on a High State for 10 µs. That will send out an 8-cycle sonic burst which will travel at the speed sound and it will be received in the Echo pin. The Echo pin will output the time in microseconds the sound waves travelled.

For example, if the object is 10 cm away from the sensor, and the speed of the sound is 340 m/s or 0.034 cm/µs the sound wave will need to travel about 294 u seconds. But what you will get from the Echo pin will be double that number because the sound waves need to travel forward and bounce backward. So in order to get the distance in cm we need to multiply the received travel time value from the echo pin by 0.034 and divide it by 2.

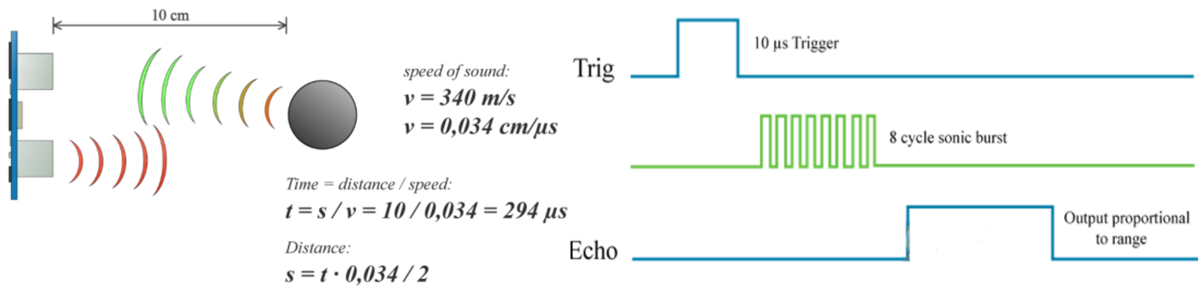

Figure 3.5 Working of Ultrasonic Sensor

3.3.3 NodeMCU

Figure 3.6 NodeMCU 12-E

NodeMCU is an open source IoT platform. It is basically a development kit that consists of the ESP8266 Wi-Fi SoC from Espressif Systems, and hardware which is based on the ESP-12 module. It can be directly programmed as a controller but in our project, we will be using it as a Wi-Fi shield. The WiFiEsp library allows an Arduino board to connect to the internet. It can serve as either a server accepting incoming connections or a client making outgoing ones. The WiFiEsp library is very similar to the Arduino WiFi and Ethernet libraries, and many of the function calls are the same.

3.3.4 Turn Control System

In order to make perfect 90 degree turns to the left or right direction which was a very important requirement in our project we used a closed loop control system using a magnetometer and servo motor. It uses a TowerPro SG90 Servo which is used to turn a QMC5883L Magnetometer to the right or left directions precisely.

Figure 3.7 QMC5883L Magnetometer and TowerPro SG90 Servo Motor

The Turn Control System is explained in the flowchart showed in the figure below.

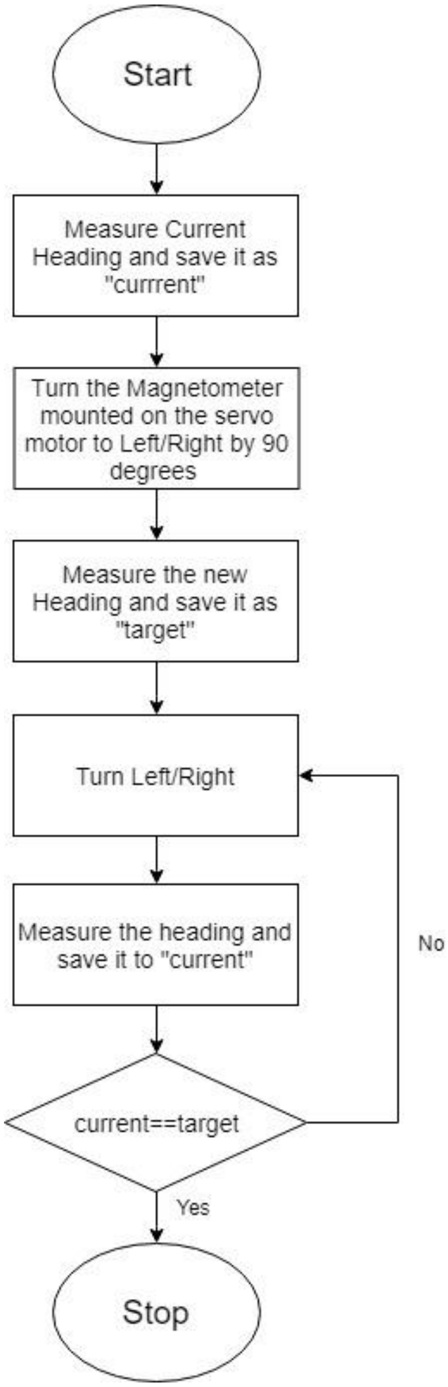

Figure 3.8 Flowchart of the Turn Control System

3.3.5 Motor Control System

The Motor Control system consists of a L293D Motor Shield which is used to control the 2 Johnson Motors. L293D consist of two H-bridge. H-bridge is the simplest circuit for controlling a low current rated motor. The Motor Shield consists of 2 pairs of input pins each pair used to control one motor,2 pairs of output pins each connected to one motors and a Vcc and GND pin. The Table 3.1 below shows the movement of the motor based on the logic applied to the input pins.

Table 3.1 Truth Table of L293D Motor Driver

Input Pin 1	Input Pin 2	Result
0	0	Stop
0	1	Anti-Clockwise Rotation
1	0	Clockwise Rotation
1	1	Power Supply Short

3.3.6 Firefighting System

Our Robots are equipped with a simple yet effective firefighting system which consists a tank holding water (Extinguishing Agent), a submersible water pump, and a relay to control the pump.

Figure 3.9 Submersible Pump(left), 5V Relay(centre) and Water Tank(right)

3.3.7 Arduino Mega 2560

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

Figure 3.10 Arduino Mega 2560

The functionality of the Robot as described above has been implemented using Arduino IDE 1.8.1. In order to enhance reusability and readability of code we have used the following libraries.

Table 3.2 Libraries used for interfacing the Hardware Components in Arduino code

Component	Library
HC-SR04 Ultrasonic Sensor	NewPing
TowerPro SG90	Servo
NodeMCU	WifiEsp
QMC5883L Magnetometer	QMC5883L

3.3.8 Functionality and Communication Interface of the Robot

The Robot connects to a Wi-Fi Network and only after successful connection the Magnetometer will point properly for the robot.

Wi-Fi Network Name – Redmi, Password – 1234567890

Every Robot is assigned a unique IP Address by the Network. The following table gives the IP Address of the 3 Robots.

Table 3.3 IP Address of the Robots when Connected to the Wi-Fi Network-Redmi

Robot1 (Green Robot)	http://192.168.43.84
Robot2 (Yellow Robot)	http://192.168.43.42
Robot3 (Blue Robot)	http://192.168.43.206

The Table below shows the different HTTP GET calls that can be made to the Robot and the corresponding action

Table 3.4 Action performed by the Robot for Different HTTP GET Requests

GET Call	Action	Example
/F	Move Forward	http://192.168.43.42/F
/B	Move Forward	http://192.168.43.42/B
/L	Move Forward	http://192.168.43.42/L
/R	Move Forward	http://192.168.43.42/R
/M	Turn on Fire Extinguisher	http://192.168.43.42/M
/I	Ultrasensor Data	http://192.168.43.42/I
/	Flame Sensor Data	http://192.168.43.42/

3.4 Software Implementation of Control Algorithm for the Swarm

In our project we are developing a Swarm Control Algorithm for Firefighting that is derived from the Glow-worm Swarm Optimization Algorithm. The major differences between our Algorithm and Glow-worm Swarm Optimization are

- Luciferin is used to mark obstacles and the robots move away from it.
- The bright beacons are the fire locations and are initially present in the environment

Since the Warehouse will obviously have goods arranged in a fixed order we can obviously hardcode the arrangement of them. The Agents i.e. the Robots are pre-deployed on the Environment/Warehouse at certain locations in the warehouse in any orientation. These positions as well as the orientation of the robots is to be entered into the program when the system is initially setup. When Fire is detected the locations are passed to the program which will first determine which robot is closest to the fire. After selecting a robot to a specific fire, the shortest path which the robot should take so that it shall reach the fire as soon as possible is computed using a hybrid of a ASTAR and DSTAR planner. After this the path is followed by the robot. Every time the robot moves from one grid location to another grid location we will use the ultrasonic sensors to update the environment for the presence of any dynamic obstacles. If any obstacles are detected, they will be updated inti the map and we shall determine if they occur on the path planned for the robot. If the obstacle is on the path, then a new path is planned for the robot else the robot follows the same path. Also, if the obstacle is a robot the current move of the robot is put into hold and try to move again in the next step. If the obstructing robot doesn’t move, then a new path is planned for the current robot. Once the robot reaches the fire location it reorients itself towards the fire and then engages the fire extinguishing activity. To prevent the servo malfunction, we have limited the time for which the pump is on to 3 seconds. After the fire is extinguished the robot will move back to its initial position. The path which the robot follows to move back to the initial position is not necessarily the same path it followed to reach the fire location. Once all the robots reach their initial position the current iteration is complete. The next iteration will start once the new fire location data is given to the swarm system.

The locations in which the dynamic obstacles are detected will be assigned the highest concentration of luciferin value (1) and this value will either be reinforced in the subsequent iterations if the obstacles are detected in future iterations else the luciferin value will decay at a rate of 0.1/iteration.

The Algorithm has been implemented in MATLAB. We have also used a lot of inbuilt graphics functions of MATLAB to show the status of the environment in Real-Time in the Central Server. The code is easily scalable by making changes to a small number of variables. The list of variables is given below.

- nr – Number of Robots in the Swarm.
- nf – Number of Fire Locations in the Environment.
- color – Colours to be assigned to the Robots in the Swarm
- robotip – IP Address of Robots in the Swarm
- envdata – Map Data of the Warehouse
- objdata – Dynamic Obstacle Data sensed by the Robots in the Swarm
- decay – Luciferin Decay Constant
- initial_pos – Initial Position of the Environment
- fire_pos – Fire Locations in the Environment
- fire_assignment – The ID of the Fire assigned to the Robots in the Swarm
- step_distance – The distance travelled by the Robot in one step
- current_pos – Current position of the Robots in the Swarm
- dir – Current Orientation of the Robots in the Swarm
- reached_flag – Flag that indicates if the Robots have reached their respective Fire Locations.

We know that the warehouse under consideration has fixed grid location. Since warehouses already have good stored in certain areas we can directly black them out and this has been done in our algorithm itself. The figure below shows the map of the warehouse with goods. Please note that these goods can also catch fire. The Map of the warehouse can be changed by changing the variable “envdata”

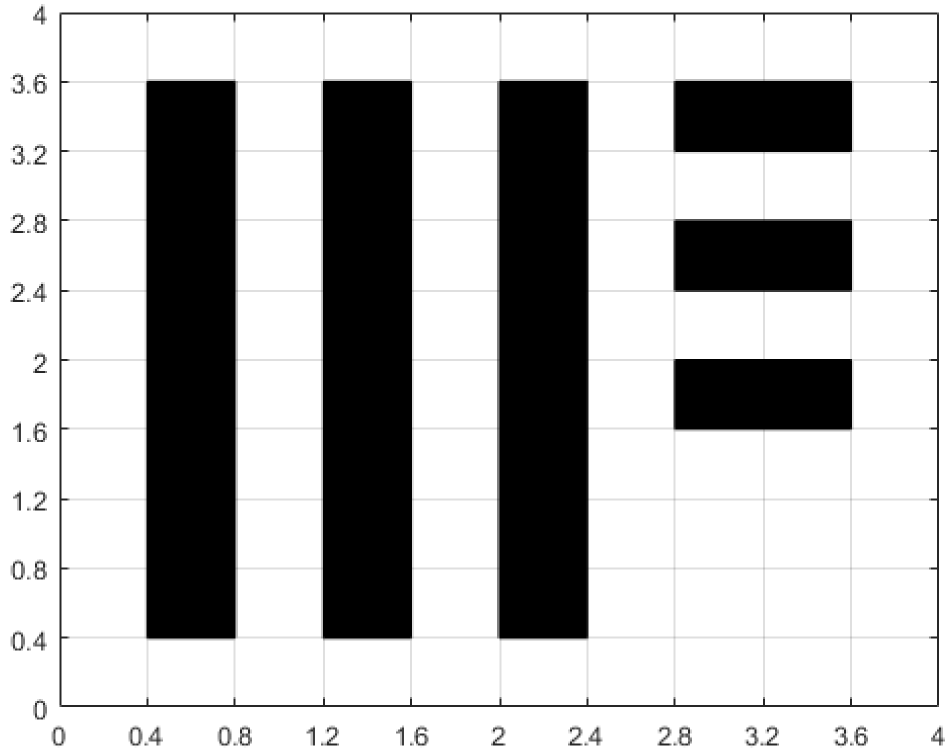

Figure 3.11 Map of the Sample Indoor Warehouse

Also let since our robots can travel only in 4 directions it is necessary to the initial position and orientation of the robots. Initial position should be given with respect to the corresponding grid position. While orientation is to be given as shown below.

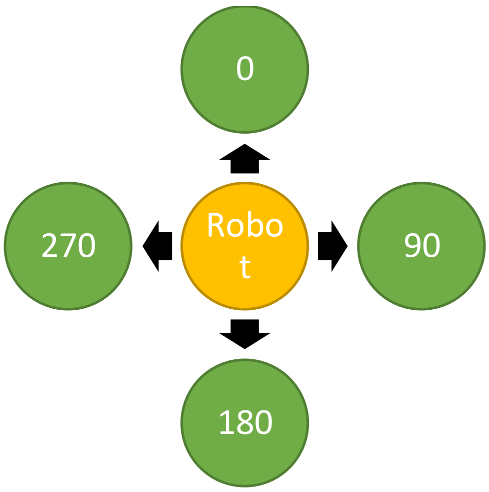

Figure 3.12 Orientation Chart of the Robot

The Flowchart of the Algorithm is show in figure below.

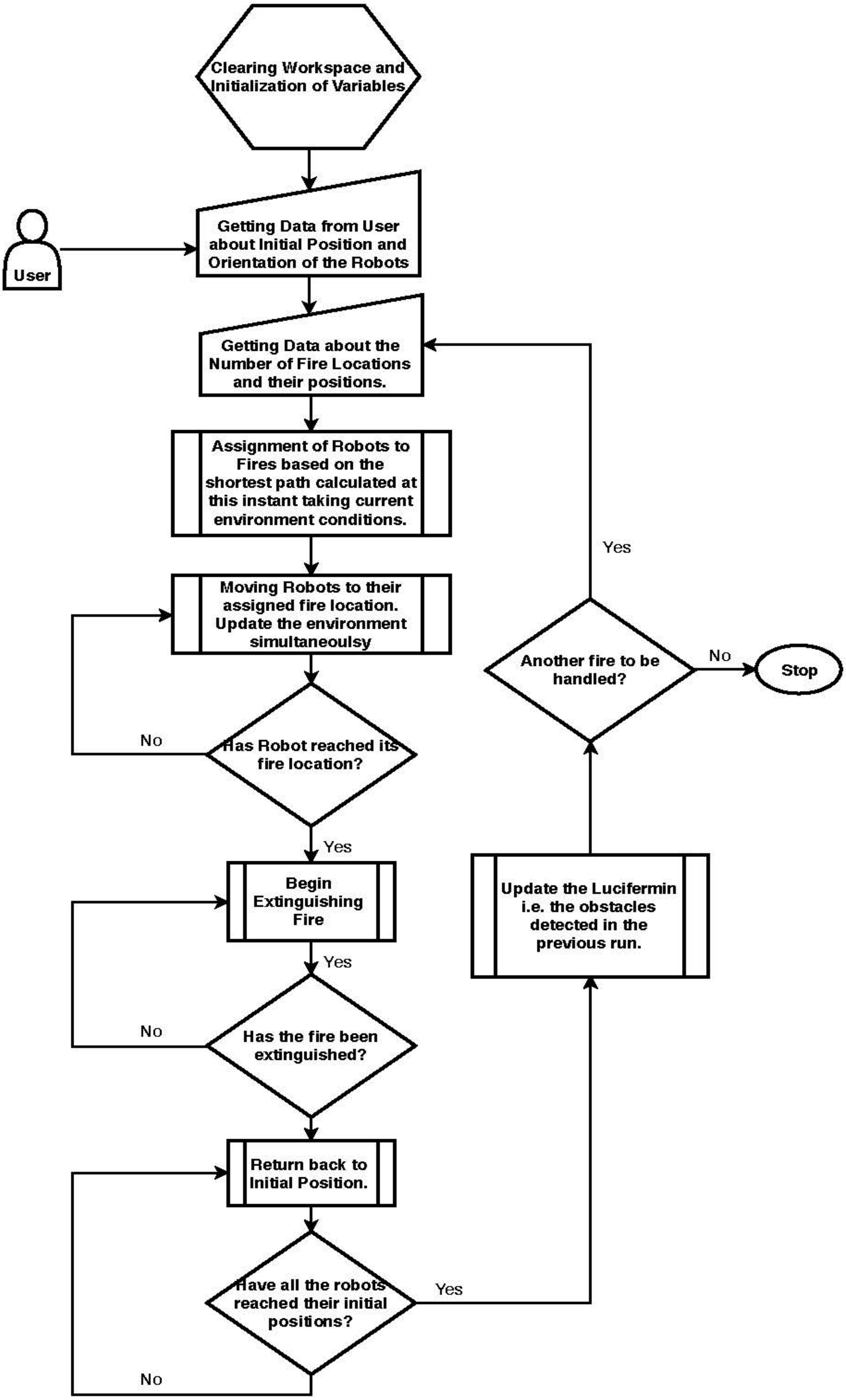

Figure 3.13 Flowchart of the Swarm Control Algorithm

Chapter 4 Results and Discussion

4.1 Results

Since Our System is capable of handling up to 3 fire locations we have shown all the cases.

4.1.1 Case 1 – Three Fire Locations

Commands Given

Enter the Initial Position of Robot1 :-1

Enter the Orientation of Robot1 :-90

Enter the Initial Position of Robot2 :-10

Enter the Orientation of Robot2 :-0

Enter the Initial Position of Robot3 :-100

Enter the Orientation of Robot3 :-0

Do you want to enter information about fire position? [y,n] :- 'y'

Enter the Number of Fire Locations in the System :- 3

Enter the Location of Fire1 :-41

Enter the Location of Fire2 :-39

Enter the Location of Fire3 :-91

Status of Map

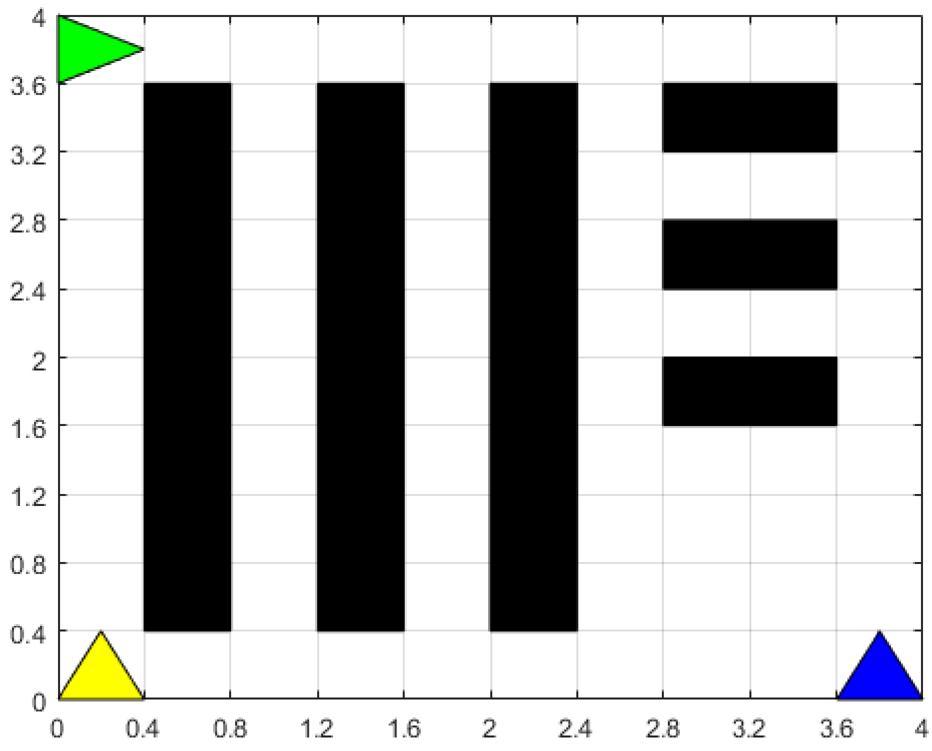

Figure 4.1 Map after the Positions of the Robots are given.

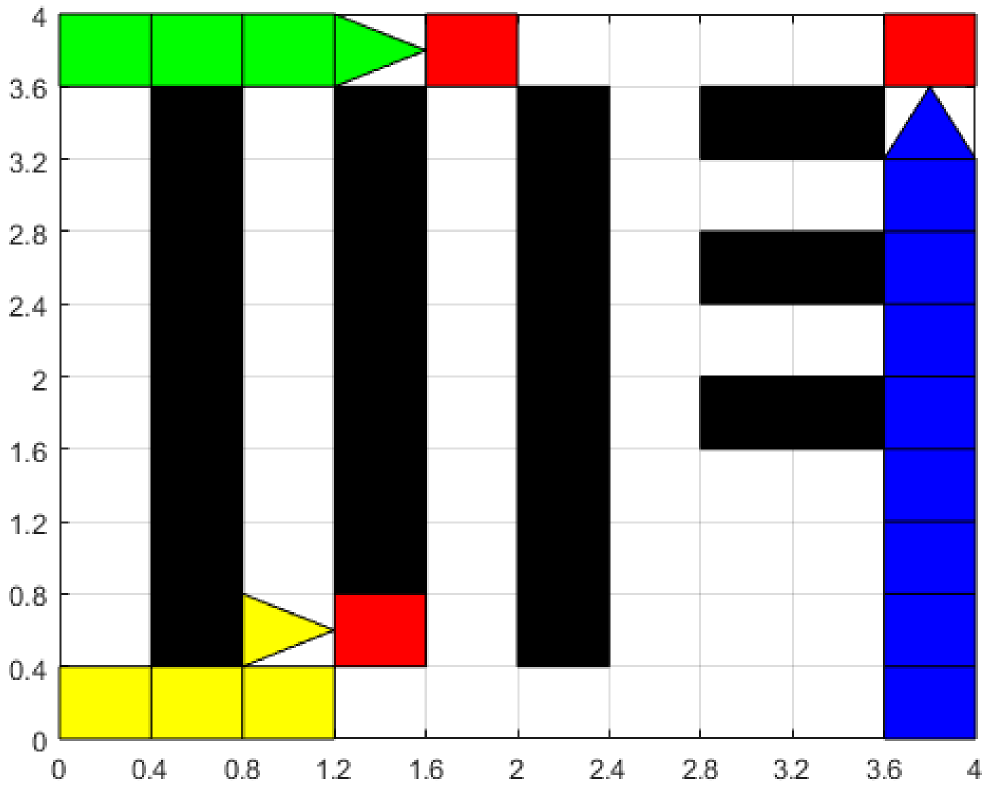

Figure 4.2 Map when the Robots have just reached their respective fire locations (Case 1)

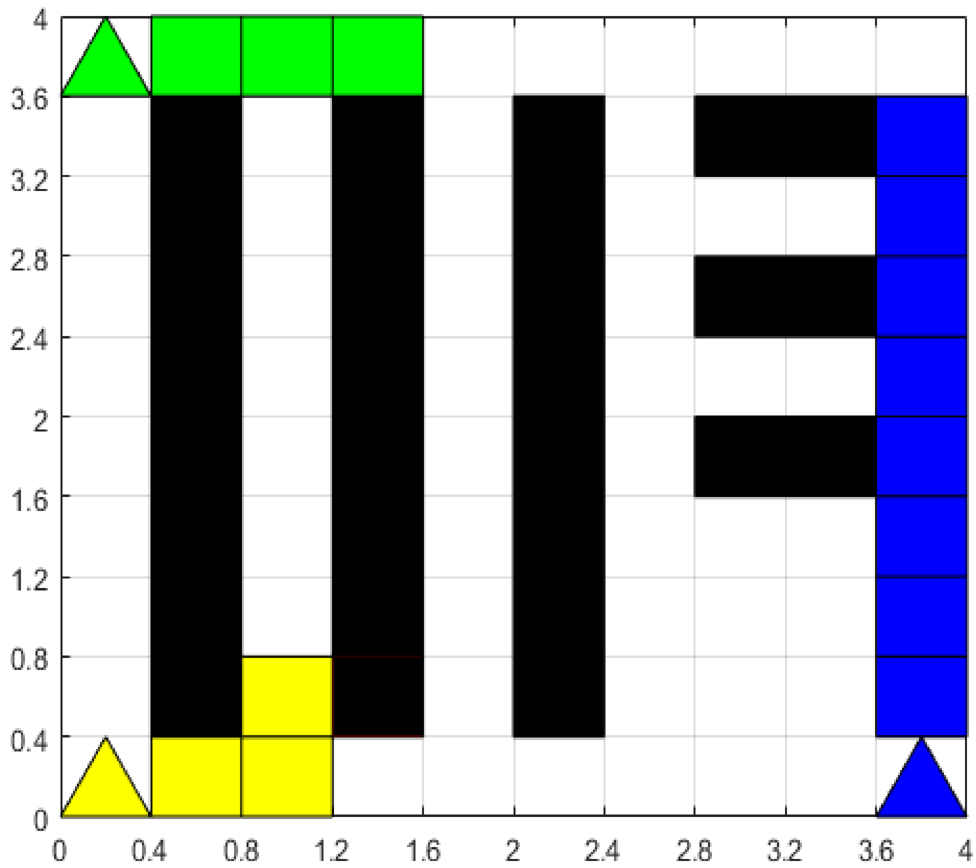

Figure 4.3 Path taken by Robots to reach Initial Positions after fire extinguished (Case 1)

4.1.2 Case 2 – Two Fire Locations

Commands Given

Do you want to enter information about fire position? [y,n] :- 'y'

Enter the Number of Fire Locations in the System :- 2

Enter the Location of Fire1 :- 45

Enter the Location of Fire2 :- 65

Status of Map

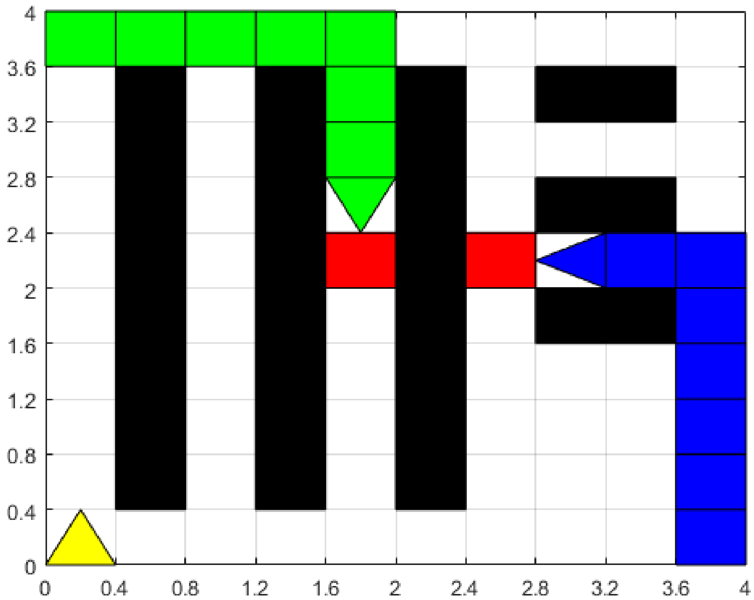

Figure 4.4 Map when the Robots have just reached their respective fire locations (Case 2)

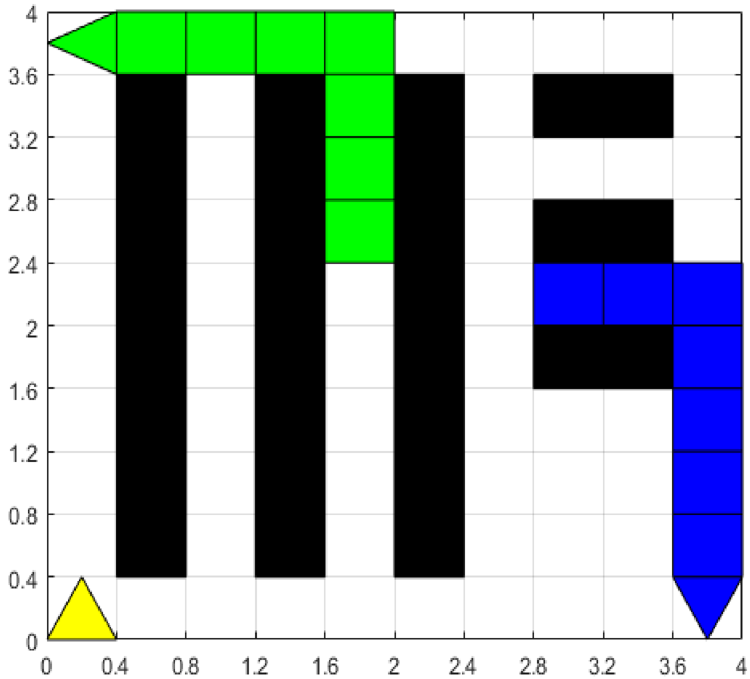

Figure 4.5 Path taken by Robots to reach Initial Positions after fire extinguished (Case 2)

4.1.3 Case 3 – One Fire Location

Commands Given

Do you want to enter information about fire position? [y,n] :- 'y'

Enter the Number of Fire Locations in the System :- 1

Enter the Location of Fire1 :-73

Status of Map

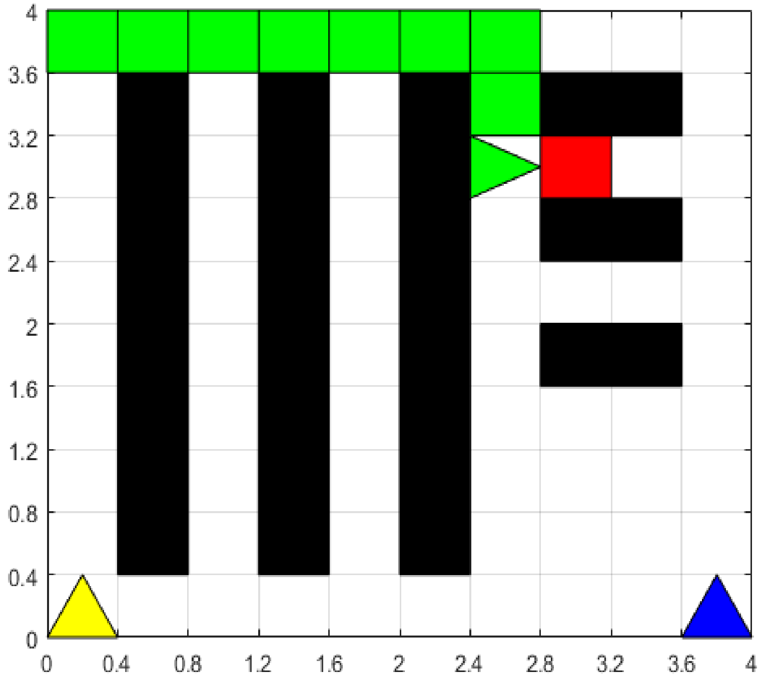

Figure 4.6 Map when the Robots have just reached their respective fire locations (Case 3)

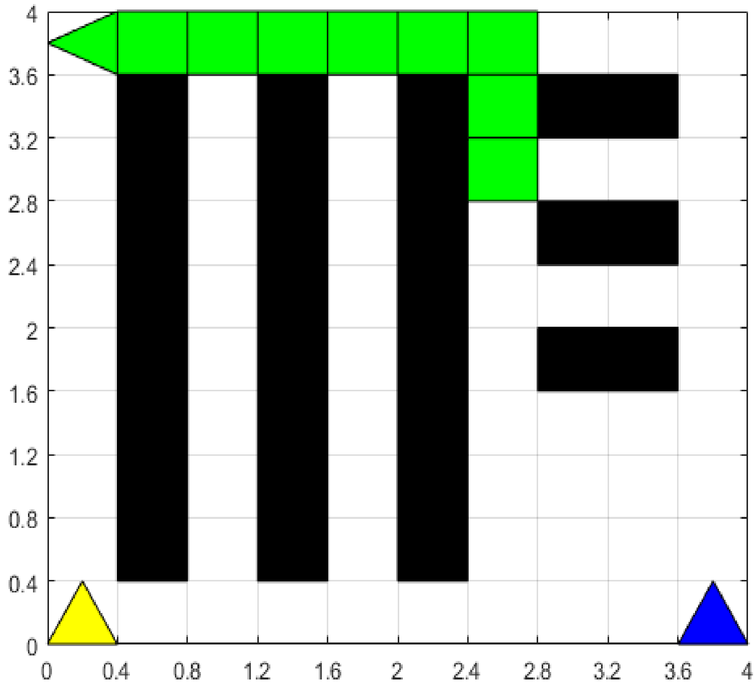

Figure 4.7 Path taken by Robots to reach Initial Positions after fire extinguished (Case 3)

4.2 Discussion

In the above 3 cases we have recorded the following response time for reaching the fire location. We are taking simulation times into account as real response time also takes in factors such as battery of the robot, network delay, time taken to for the robot to turn/ move one unit, etc.

Table 4.1 Response Time of the Swarm System for different cases

Case	Response Time in seconds
Three Fire Locations	14.284549
Two Fire Locations	12.284793
One Fire Location	11.234535

The algorithm is performing as expected. It is able to handle multiple fire locations using the swarm of robots. It directs the nearest robot to the nearest fire location.

Also, we have to note that the Response Time of the System is completely flexible as multiple factors contribute toward it such as:

- Number of Robots in the System
- Area of the Indoor Environment/Warehouse
- Length of the Grid Location

4.2.1 Issues with the Robots

- Uneven thickness of rubber tires on the wheels, Load balancing and wheel alignment issues are causing the robot not to move forward properly.
- Servo motor malfunctions when the submersible pump is switched on.
- Small Buffer size of the NodeMCU causes only a maximum of 3 calls to be made to the robot in a span of 3 seconds.
- When the Arduino Board is powered up the Bootloader loads the program into the memory. However, while this happens all the pins are made high due to which the motor is activated.

Chapter 5 Conclusion and Future Work

5.1 Conclusion

The three intended features namely, **Robustness, Flexibility and Scalability** have justified the creation of swarm intelligent systems by displaying the ability to continue the completion of a task despite the loss of an individual in the swarm, allowing a modular approach to achieve different tasks based on dynamic environment and by providing the experimental proof that the addition of new robots to the swarm is seamless and allows the swarm to increase capacity without extra configuration, with little or no human intervention.

Three prototype swarm robots were built with the required physical features to assist in extinguishing the fires. The appropriate algorithm for implementing swarm pattern and communication between the robots was embedded into them along with fire detection & extinguishing methodology.

Simulation of the above system in various scenarios to understand the performance of the algorithm was achieved including addition of suitable adjustments to enable them to adapt to their surroundings.

This resulted in the successful implementation of Swarm Systems to fight fires using the modified GSO and justified that **Superior Performance** can be achieved when compared to conventional firefighting systems.

5.2 Future Work

During the course of implementation, we had come across of a lot of innovative ideas and concepts that can also be used with our system or integrated with them. We have listed some of them below:

- Intercommunication between Robots can be implemented to provide assistance for unmanageable fires.
- The robots can also be equipped with 2 axis fire suppressing nozzle for max firefighting capability.
- Upgrading Hardware Components of the Robot so that its performance can closely match with Firefighting Trucks. Some of the hardware components that can be replaced are given in a table below.

Table 5.1 Suggested Hardware Improvement of the Robot

Current Hardware Component	Possible Replacement
Arduino Mega 2560	Raspberry Pi or Beagle Bone
HC-SR04 Ultrasonic Sensor	Maxxsonar Ultrasonic Sensor
Flame Sensor	IR Imaging Camera
Johnson Motors	Maxon DC Motors with Inbuilt Encoders
Submersible Water Pump	High Pressure Pump
12V DC Battery	High Capacity Lithium Polymer Battery

Also, we can use LIDAR and GPS for Enhanced Navigation.

- A Backup Network using x-BEE or Bluetooth can be implemented so that the system can still function if the main Wi-Fi network is down.
- Ability to go and refill Extinguishing Agent autonomously.
- Ability to use different extinguishing agents.
- The System can be used to fight forest fires by integrating it with data from Earth Observation Satellites such as NASA Terra which provide real time information regarding Forest Fires.
- The System can also be integrated with Crowd Control Systems such as Active Denial System to ensure that civilian population are kept out of harm’s way.
- The System can also be integrated with Robot Security Systems, etc.
- The System can also be integrated so that it can used in tandem to support firefighters.

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