Multiple oriented robots for search and rescue operations

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Abstract. Search and rescue (SAR) operations in a tragedy affected area is challenging. The rescue robots helps in the exploration of unknown, confined and cluttered environments. Multiple robots are developed will to explore the disaster affected region and will be able to detect any people or living beings present there. The robots have living beings as their targets in tragedy affected area. The multiple robots deployed in the field, traverse through the tragedy affected area. A novel algorithm has been developed which helps in finding the target. The rescue robots are programmed to find the shortest and less obstacle path to reach the target. Due to the tragedy affected environment, the robots decides the moving direction based on the information gathered by sensors such that the optimal path between start and goal positions can be found. The path to target by the robots are shared among them and best path is chosen among them. The robots explore and searches the region avoiding the obstacles and whenever it comes into contact with a living being it shares the information among other robots. The CO2 level of the particular region is also checked to know whether the person is in breathing state. The algorithm will be developed in order to increase the pace of the search and to locate the living being. The SAR robots have application over tragedy affected areas like earthquake, avalanche, etc.

1. Introduction
Swarm Intelligence algorithms are very popular in present which solves complex problem in field of engineering, technology, management and science. The algorithm which is based upon natural biological factors are called Nature Inspired Algorithms (NIAs). The NIA acts similar to the natural conduct of social living entities like fish, honey bees, birds, termites, ants etc. The concept of swarm intelligence (SI) is trending nowadays and becomes an upcoming and an interesting area where new algorithms are developed in order to counter various real life issues. It is based upon the collective conduct or actions of living things which lives as a group. These animals use their ability of societal knowledge to solve different kinds of day to day chores. The advantage of these swarm optimization strategies are the ability to communicate among the individuals within their group. Swarm intelligence (SI) methodologies or strategies has the capability to find a solution for difficult and complex actual world issues as the upcoming study has been proposed.

Nature provides us the knowledge to find out problems with different levels of difficulties efficiently with higher success. NIAs are influenced by numerous biological factors and NIAs can be easily classified based upon their source of influence or motivation. The NIA can be better classified in to Evolutionary, Neural, Probabilistic, Stochastic and Swarm Algorithms.
The swarm algorithms have wide range of applications such as Robotic control or navigation, Automation, self driving cars, Robot assisted surgery, Animation, computer games, Folding of protein, Safety and accessibility in computer-aided architectural design. Search and rescue operations by autonomous robots are also one of the crucial application of swarm algorithms are Search and rescue operations in a tragedy affected areas which are highly demanding because of the extremely filled with debris and unstructured character of the environments. However, in particular scenarios, the duty of rescuing people from the debris can be more dangerous because the instability of damaged structures or the presence of dust, toxic chemicals or radiation. Approaching a building which has been collapsed sometimes needs to be enter in to voids, which may be smaller or deeper for fire fighters or rescue people and rescue dogs. In order to overcome these issues rescue robots has been developed in order to help workers who are involved in the Search and Rescue(SAR) operations. Here in this proposed system a new algorithmic approach has been introduced which helps in finding the target of a search robot. A simulated environment is provided which shows the safe robot searching for its target and finding it in an efficient manner.

2. Literature Survey
Path planning (PP) is an important procedure in Multi-Robot Systems (MRS), it has numerous applications in present. Path planning may be represented as searching for a shorter and an efficient path between the target and goal avoiding collision with the obstacles in the path [1]. Numerous methods has been given to find Path Planning problems and generate an efficient and less obstacle path in MRS which is still hard because of its nature and higher complexity. The methodologies can be categorised to two groups: 1. Offline which is global algorithm and 2. online which is local algorithms [2]. In global, the information regarding the test environment will be known before. In case of local algorithm where they will not be aware about the environment. Hence, the algorithms will be depending upon the information that is obtained by the sensors.

Cell decomposition and partitions of roadmap comes under offline approach and the obstacle free cells which will be taken as the nodes in the workspace. The path among the nearby cells are denoted by the graph’s edges [3]. The optimal path is found out using an algorithm for graph searching. For higher dimension space applications offline method may not be suitable. Hence, these methods may be trapped in a local minima of an environment consisting of multiple solutions.

Some of the online methods are RRT and potential fields has been approached to find the Path planning problems in a tragedy affected dynamic environments. These online methods are able to give the strength to respond to the changes of the robot while it is moving. Therefore, based upon these factors like higher dimensions of the search space, obstacle’s shape, and the complexity of robot’s kinematic and dynamic models [5], Path Planning may not be found by the given computational resources.

By using heuristic methods which has the characteristic traits from the nature or social systems like particle swarm optimization (PSO), Ant Colony Optimization (ACO) and Genetic Algorithm (GA) which are highly famous and effective to find Path Planning problems. The mentioned methods are more likely to get better performance when compared with the classic methods, mainly the more complex environments. [6] The main disadvantages of heuristic method is that in many of the existing algorithms, the environment is known totally or partially. Moreover, these methods were approached for a single robot system. In order eradicate these above provided disadvantages, a heuristic method is applied for finding the complex path.

Mobile search and rescue robots may be made to search in a rugged and difficult urban search and rescue (USAR) environments where they will be able to help explore unknown and tragic affected environments searching for trapped people. Advantages of these robot is Urban Search and Rescue(USAR) helps in lowering the work of rescue workers and efficiently improves their situational awareness of the environment. Moreover, rescue robots may be utilized as a necessary extra agents to assist the search for living beings during such critical tasks. To mention these exploration problem for urban search and rescue environments, autonomous robots are needed to move through various
locations of a complex environments to map the tragic affected environment and locate the victims who has been trapped. Simultaneous localization and mapping (SLAM) methods are used to map the places where the robots are exploring. Presently the common method used for exploring different scenarios is frontier exploration, Here, a search robot is made to travel through the boundaries of a completely explored environment. Frontier exploration method is usually based upon cost or utility-based performance metrics. These methods get optimize for known certain scenario and an objective which is provided to it such as highly minimizing distance or increasing information gain. USAR(Urban Search and Rescue) environments which are damaged due to tragedies that will be highly unpredictable as the environment layout can be significantly changed after the disaster, it makes the reliability on a known environment’s layout not dependable [2]. Moreover, USAR environments which varies from one another are not similar.

To show disadvantages of machine learning and existing frontier explorations approaches, this paper uses deep learning for exploration problem of the robot in applications of USAR. a novel DRL network architecture for frontier exploration which is benefitted from the above contribution consists design that makes a search robot automatically explore unknown complex areas of the deployed environment. An unique exploration approach is developed combines frontier exploration and DRL which allows a search bot to gain knowledge from its own experiences, while being able to generate exploration strategies for varying unknown tragic affected environments. The main aim of this method increases the information gaining capability of the robot during exploration circumstance. This is highly likeable trait which allows to find the trapped living beings within a tragedy affected area by the robot as fast as possible.

3. Methods

3.1. Particle Swarm Optimization

PSO (Particle Swarm Optimisation) got its popularity due to its simple and effective nature. In PSO, velocity and random positions are provided to the swarm particles. The movement of particles are based upon the parameters provided. Each and every individual swarm particles move forward to the best-found position among the group that is called Pbest and the best-found position among the swarm member is called the Gbest. The velocity and position for the ith particle in tth iterations are represented by xi(t) and vi(t), respectively and can be calculated.

Psuedo code:
For individual particle
    initializing particles with random number
End
Do
    For individual particles
        Calculate fitness values
        If fitness value is better than that of best fitness value(pbest) in history
    End
Choose particle with best fitness value of all the particles as the gbest
For each particle
    Calculate particle velocity according to velocity update equation
    Update particle position according to position equation
End
While maximum iterations or minimum error criteria is not allowed
3.2. Artificial Bee Colony Algorithm
Bees performs numerous smart works, where foraging is one among the crucial work in the bee colony. In the foraging process collective intelligence is used, which is depended upon the interactions and communication of the different bee types among themselves. Bees are specialized based upon the work which has been assigned to them. In an actual bee colony or bee hive, bees has been classified into three types where foraging tasks are assigned are scout, employed and onlooker bees. Initially the scout bees will be searching for the new food sources that available in the environment and the found nectar will be stored in the hive. New sources which has been discovered are then exploited by employed bees and they will be communicating about the gathered knowledge along with the onlooker bees where they will be waiting in the hive or bee colony. Food source which are chosen are reached by the Onlooker bees based upon the information given to the employed bees. When depletion occurs to the source, then its left out and the switching of role occurs from onlooker to a scout bee. Bees tries to increase the amount of nectar stored in bee hive by finding the most resourceful sources in the environment while foraging task. Artificial Bee Colony(ABC) algorithm helps in simulating the foraging behaviour of natural honey bees. Food sources and its locations depends upon the problem’s parameters, while finding the preferred area of the more resourceful or profitable food source is an optimization problem. In this algorithm the fitness of a parameter vector represents the nectar amount of the solution.

Main steps of the algorithm are given in Alg. 1:

Pseudo-code:

1: Initialize
2: Evaluate
3: cycle=1
4: repeat
5: Employed Bees Phase
6: Calculating the Probability for Onlooker bees
7: Onlooker Bee Phase
8: Scout Bee Phase
9: Store the best solution so far
10: cycle=cycle+1
11: until cycle=Maximum Cycle Number

3.3. A* Algorithm
A* or A-star is one of the search algorithms which is used to find solution for numerous problems, where path finding also comes under one of the applications. For pathfinding, A* algorithm continuously examine the highly efficient unexplored or unknown location it has seen. When an area or a location is discovered, the algorithm ceases its action if that given location is the actual goal; or else it will take note of the neighbours locations for more explorations. A* one of the most popular path finding algorithm in game AI (Artificial Intelligence)

Pseudocode:
1. Initial node gets added to open list.
2. Cycle repeat:
   a. Searches node with lowest f value on the open list. Refer this node as the current node.
   b. Switch it to closed list.
   c. For each node which is reachable from the present node
      i. If in the closed list, ignore.
      ii. If not on open list, add it to the open list. Make the current node as the parent of this node. Record values of f, g, and h of the node.
      iii. If already in open list, check whether it is a better path. If so, change the node’s parent to the
current node, where $f$ and $g$ values are recalculated.

d. Stop
   i. Add the target node to the closed list.
   ii. Where the target node cannot be found and the open list is empty.

3. Trace backwards starting from the target node to the starting node.
   That is the required path.

4. Methodology

Here in this proposed system a social behaviour algorithm i.e the Artificial Bee colony algorithm or 
ABC algorithm is used along with a modified evolutionary programming algorithm. The algorithm helps in path planning and helps to reach the goal in an efficient manner. The artificial bee colony algorithm helps in the finding of collision free path. Thus, it helps in the avoidance of obstacles. The evolutionary programming algorithm helps in optimisation of the path. Thus the above algorithm helps the robot which has been deployed in an unknown region to find a goal by avoiding the obstacles and reach it efficiently when compared to Artificial Bee colony algorithm and ABC-EP algorithm.

The environment for the algorithm are simulated using MATLAB code in a MATLAB R2018a software. Here we’ll set the parameters for the ABC algorithm were the population will be fixed to 500. The calculation of path will be done means of 10 iterations. The upper decision lower and upper bound are set. After finding the fitness value, the best cost for each iteration is updated repeatedly.

Modified ABC-EP Algorithm

The Evolutionary Programming (EP) algorithm helps in the choosing of the right path from the starting point to the goal. It helps in the determining of the movement of the robot in an unknown field by getting the information from the field and based upon the input the path has been laid. The weight function is an important factor determining the movement.

$weight = 0.5 + weight + 0.5 \times (norm(path(:,i-1) - path(:,i)))$.

The above weight function is used in one of the variant of Artificial Bee Colony known as ABC with constrained optimization is combined along with the Evolutionary Programming algorithm to get the desired results. Here are the steps involved in the algorithm, the initial population is set to a desired value and the number of iterations to be performed is set. By means of the position of the bees in the region the cost value is calculated. This is done for each and every path it takes and the cost function gets updated. The cost function which is lesser among the calculated values based upon the path it has travelled will be taken as best cost value. Obstacles are avoided by means of collision avoidance. The evolutionary programming helps in calculating the smoother path and short path.

5. Results

Here we have created various complex environments, where the robot is made to search for its goal. The algorithms such as Artificial Bee Colony algorithm, ABC with EP algorithm and ABC with modified EP algorithm are tested to find the path between the robot and the target. The work space for the environment is taken in an 100x100 grid. For each algorithm the best cost value has been obtained which reflects the efficiency of the algorithms. Here in each of the environments provided the robot is deployed in the field and made it to traverse through the region. It avoids the collision with blockades that are present in the path of the robot and then reaches the required goal.
Environment-I

Figure 1. ABC.

Figure 2. ABCEP.

Figure 3. ABCMEP.

Environment-II

Figure 4. ABC.

Figure 5. ABCEP.

Figure 6. ABCMEP.

Environment-III

Figure 7. ABC.

Figure 8. ABCEP.

Figure 9. ABCMEP.
Environment-IV

The simulations are simulated using MATLAB code in a MATLAB R2018a software. Here various environments are created and by using ABC, ABCEP, ABCMEP algorithms, path finding is done. For each simulation, an optimal path is found out based upon the respective algorithms and the best cost values are found. While execution, the path is found by calculating the cost with multiple iterations, and from that, the best cost value is obtained for each environment.

Table 1. Comparison of best cost values.

| Environment       | ABC    | ABCEP  | ABCMEP |
|-------------------|--------|--------|--------|
| Environment-I     | 0.8741 | 0.1216 | 0.0927 |
| Environment-II    | 0.0246 | 0.021  | 0.0074 |
| Environment-III   | 0.3359 | 0.1260 | 0.0040 |
| Environment-IV    | 0.0213 | 0.0174 | 0.0062 |

6. Conclusion
In this paper, we presented a comparison among three algorithms such as ABC, ABCEP, and ABCMEP, where we have listed their best cost values for different environments. Here, we can conclude that the best cost value for the ABCMEP is better than that of the other algorithms. Thus, ABCMEP is the better of the three algorithms tested for path planning.

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