Modeling the Coordination of a Multiple Robots Using Nature Inspired Approaches

Mauro Tropea, Nunzia Palmieri and Floriano De Rango

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DIMES Dept, University of Calabria
e-mail: (derango, n.palmieri, m.tropea)@dimes.unical.it

Abstract. The work focuses on the problem of multiple robots coordination in search and rescue mission. In particular, decentralized swarm techniques, that use mechanisms based on Swarm Intelligence, are presented. Essentially, two approaches are compared. The first uses a one-hop communication mechanism to spread locally the information among the robots and a modified firefly meta-heuristics is proposed. The second approach, is based on a multi-hop communication mechanism based on Ant Colony Optimization. We have conducted experiments for evaluating what is the best approach to use considering different parameters of the system.

Keywords: Multi robots coordination, Nature inspired techniques, Swarm intelligence

1 Introduction

Over the past decade, the field of distributed robotics has been investigated actively, involving multiple, rather than single, robots. The field has grown dramatically, with a much wider variety of topics being addressed. However, the use of multiple robots poses new challenges; indeed, the robots must communicate and coordinate in such a way that some predefined global objects can be achieved more efficiently.
Swarm robotics is a new approach to the coordination of multi-robot systems which consists of large numbers of mostly simple physical robots. It gets inspiration from Swarm Intelligence (SI) to model the behaviour of the robots. SI-based algorithms are among the most popular and widely used. There are many reasons for such popularity, one of the reasons is that SI-based algorithms usually sharing information among multiple agents, so that self-organization, co-evolution and learning during iterations may help to provide the high efficiency of most SI-based algorithms. Another reason is that multiple agent can be parallelized easily so that large-scale optimization becomes more practical from the implementation point of view [1][2][3][4]. Recently, SI-based algorithms have applied also in search and rescue operations to coordinate teams of robots [5][12]. Some years ago, a novel technique called FireFly algorithm has been proposed to realize a multi-modal optimization for hard-decision problem [6]. Its basic version has been modified and extended to fit search and rescue operations in the field of mobile robots such as presented in [7][8]. Moreover, a distributed wireless protocol has been

also proposed in [9] to speed up the execution time of multiple task such as exploring and disarming task. In the past years also the exploration of un-unknown area through mobile robots has been considered using ACO inspired approaches [10][11] also considering hazard environment with limited communication capability such as in [12].However, few of the proposed approach in exploration and target finding, considered energy consumption as evaluation metrics to estimate the effectiveness of the proposed approach. In [13][14][15][16] are presented some distributed protocols applied in the context of mobile ad hoc networks where the energy issue is considered and some multi-objective formulation for the path finding and bio-inspired solutions have been proposed. Recent work considered also the SI-algorithms applied in the decision making process and security such as presented respectively in [17][18].

Main contributions of the paper are listed below:

1. A math formulation for the search and rescue operations to mine disarming in an un-known area is presented. This formulation considers some constraints in the problem such as minimum number of robots to perform the disarming task and the discovery of all cells in the unknown area.
2. Two bio-inspired techniques have been introduced evaluating their performance in terms of scalability for increasing targets and number of robots. The first one is inspired by Fire Fly (FF) algorithm and it makes use of local communication; the second one is inspired by Ant Colony Optimization (ACO) and it is based on a distributed multi-hop wireless protocol to disseminate data.

2 Problem Description

In this work, we consider a set R of homogeneous robots working in a discrete domain [7-9]. Each robot has limited sensing capabilities. The communication range of the robots is assumed to be limited, and a robot can reach another robot by a sequence of communication links. Furthermore, the robots have a limited computational power, so their cooperative strategies cannot involve complex planning or negotiations. In the area, a certain number of different targets are scattered randomly. Each target *z* requires a certain amount of robot (R_{min}) to be handled. It is assumed that there are no a priori knowledge about the targets such as locations and numbers. When a robot detects a target, it is assumed that the sensing information is perfect. Since a single robot does not have enough resources to handle the target, a coalition of robots may need to be formed to jointly handle the target *z* safely.

Table 1. Variable of the system

A	grid map and $A \subset R2$
N^R	number of robots
R_{min}	number of robots needed to deal with a target
T	set of targets
N^T	: number of targets, NT = |T|
v_{xy}^k	$\begin{cases} 1, & \text{if the robot k visits the cell of coordinates } (x,y), \\ 0 & \text{otherwise} \end{cases}$
T_e	Time to visit a cell

T_{coord}	Time to coordinate a target
u_z^k	$\begin{cases} 1, & \text{if the robot k is involved in the target z,} \\ & 0 \text{ otherwise} \end{cases}$
E_m^k	The energy consumed by the robot k for moving
E_{tx}^k	The energy consumed by the robot k to transmit a packet
E_{rx}^k	The energy consumed by the robot k to receive a packet
E_d^k	The energy consumed by the robot k to deal with a target
E_{coord}^k	Energy consumed by the robot k for coordination

$$minimize \sum_{k=1}^{N^R} \sum_{x=1}^{m} \sum_{y=1}^{n} T_e v_{xy}^k \;+\; \sum_{k=1}^{N^R} \sum_{z=1}^{N^T} T_{coord,z}^k u_z^k \tag{1}$$

s.t

$$\sum_{k=1}^{N^R} v_{xy}^k \;\geq 1 \quad \forall (x,y) \in A \tag{2}$$

$$\sum_{k=1}^{N^R} u_z^k = R_{min} \quad \forall\, z \in T \tag{3}$$

$$v_{xy}^k \;\epsilon\; \{O,1\} \quad \forall (x,y) \in A,\;\; k \;\epsilon\; R \tag{4}$$

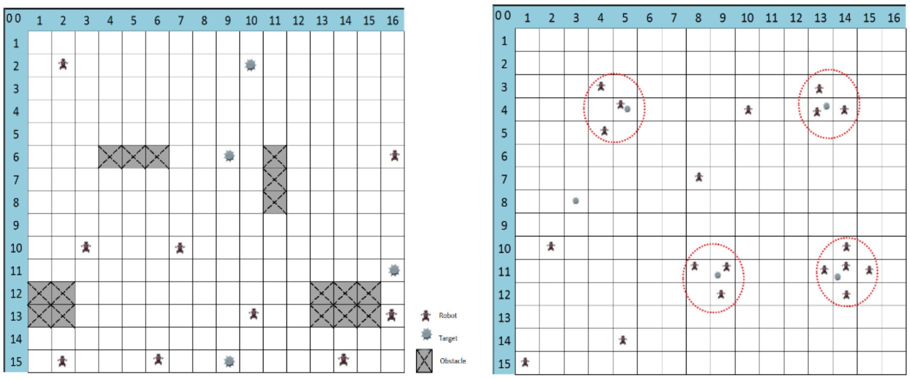
$$u_z^k \;\epsilon\; \{O,1\} \quad \forall\, z \in T,\;\; k \;\epsilon\; R \tag{5}$$

$$T_{e,} T_{coor,z}^k, E_m^k, E_{coord,z}^k \;\; \epsilon\; R, \forall\, z \in T,\;\; k \;\epsilon\; R \tag{6}$$

Eq.(2) and eq. (3) are respectively the constraints that assure that all cells need to be visited (eq.(2)) at least by one robot and the minimum number of robots requested to complete the demining task R_{min}. In the considered problem is evaluated the energy consumption of robots on the basis of the following equation:

$$E_{tot}=\sum_{k=1}^{N^R} E_m^k + \;\sum_{k=1}^{N^R} \sum_{z=1}^{N^T} E_{coord,z}^k u_z^k \tag{7}$$

Eq.(7) is useful to compute the total energy consumed by robots during the movement and in the specific task of demining. This means that the s contribution of energy accounts for the movement and the search operations whereas the second contribution considers that communication cost (transmission and reception of recruiting packets) and the demining task when the robots reaches the target location.



(a) (b)

Fig. 1. (a)A representation of the considered environment. (b) Local coalitions of robots formed through the recruitments processes

3 Multi-Robots Architecture Design

We suppose that the robots explore the area using an algorithm such as presented in [7-9]. The work treats only the problem of recruiting the needed robots in targets locations using only local spreading of the information about the detected targets.

A network architecture is created once a robot detects a target in the area and from this point that initiates communication with neighbour to neighbour.

One approach uses only one hop communication and a firefly based algorithm is used to coordinate the robots. It is called Fire Fly based Team Strategy for Robot Recruitment (FTS-RR).

The other approach regards the development of a protocol to coordinate the team. The strategy is called Ant based Task Robots Coordination (ATRC) protocols. In this case the robots exchange simple information to avoid the redundancy in reaching the targets location. The communication is multi-hop and higher number of robots can be reached to be recruited.

3.1 Coordination using a Firefly Algorithm (FTS-RR)

Concerning the considered problem, the robots that have detected a target, starts to behave like a firefly sending out help requests to its neighbourhood. When a robot *k* receives this request and it decides to contribute in the disarming process, it stores the request in its list. If the list contains more requests, it must choose which target it will disarm. Using the relative position information of the found targets, the robot derives the distance between it and the coordinators and then uses this metric to choose the best target, that is usually the closer. In this case, no forwarding of the packet is done and the communication is one hop. The approach provides a flexible way to decide when it is necessary to reconsider decisions and how to choose among different targets. For more details related to the proposed technique please refer to our previous contribution [7]

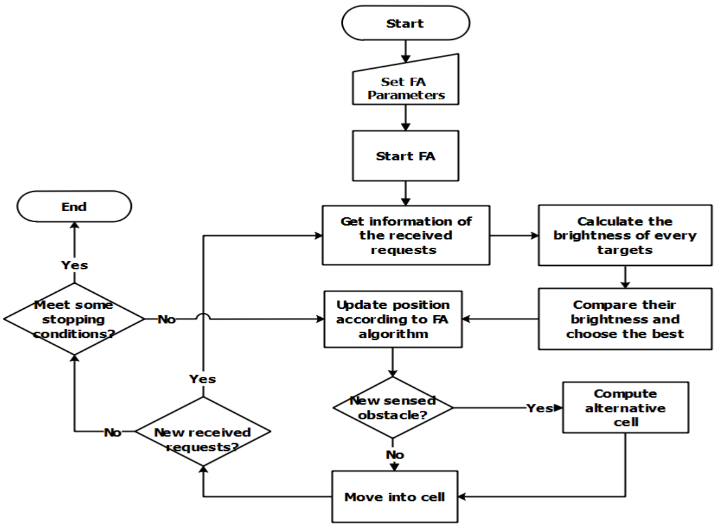


Fig. 2. The flow chart of Firefly algorithm

3.2 Coordination using an ACO routing algorithms (ATRC)

The second approach presents a network architecture for multi robots system where the information about the found targets can spread over the network of robots in a multi hop fashion. The idea is to use an ad hoc routing protocol to report the detected targets and the robots that want to help in disarming process over a MANET. Also, in this case a bio-inspired routing protocol is proposed in order to reduce the communication traffic in terms of packets and allow at the same time a self-adaptive behaviour of the robots. More specifically, the protocol takes inspiration from the ability of certain types of ants in nature to find the shortest path between their nest and a food source through a distributed process based on stigmergic communication., ACO based routing algorithms can usually set multiple paths, over which data packets can be forwarded probabilistically like ants. This can result in throughput optimization, automatic data load balancing, and increased robustness to failures.

The network of robots is created when one or more robots find a target. More specifically, the robot that has detected a target sends announcement messages that are forwarded by the other robots so that the information about the target can spread among the swarm.

The messages that a robot can send or receive are: Hello packets, Requiring Task Forward Ant (RT-FANT) that is a packet sent by the robot that has detected a target to know how many robots are available to treat the target. Requiring Task Backward Ant (RT-BANT): it is a packet that a robot sends as response to a RT-FANT; Recruitment

Fant (R-FANT): it is a packet sent by a coordinator, to the link from which came the higher number of RT-BANT responses; this link has higher recruitment probability. Recruitment Bant (R-BANT): it is a packet sent by a robot in response to a positive recruitment by a coordinator [9].

4 Simulations

In this work we want to compare the two approach trying to understand what is the best approach. Performance metrics considered for the simulation are: Total Time steps to complete the mission and the Average energy consumed by a robot for accomplishing the mission. We suppose that for treating a target it is required the work of 3 robots together. The convergence time and the energy was averaged over 100 independent simulation runs. Regarding the parameter of the techniques please refer to [7].
A computational study and extensive simulations have been carried out to assess the behaviour of the proposed approaches and to analyse their performance by varying the parameters of the problem.

Establish what it the best approach, is very hard since it depends on the context and on what is the metric most important. Tables 2-5 show the main simulation results described above, in order to try to understand, potentially, what is the best approach to use. Although the protocol, generally, can offer more benefits in terms of time, since it speeds up the mission, the consumed energy is grater since there is more communication among the team. The best approach to be used depends on many factors. Firstly, if the time is a critical variable thus using the protocol could be better to speed up the mission. Secondly if the resources of the system in terms of energy are crucial using only local interaction among the team may allow to minimize the consumed energy. Thirdly, it should be considered the conditions of the environment where the team operates. If the area is highly dynamic, hazardous and the conditions to maintain the network among the robots are unreliable, it could be suitable adapt one hop communication. In uncertain area, the robots may change decisions anytime. In these situations, using a protocol the communication in terms of packets could increase and thus lead to an overhead of communication. However, the designed protocol is based on probabilistic mechanism to forward of the packets and make decision, so it can offer a scalable and distributed solution.

Table 2. Comparison of FTS-RR and ATRC: Total Time Steps in a grid area 30x30 cells

	20 robots			30 robots			40 robots		
	1 target	3 targets	6 targets	1 target	3 targets	6 targets	1 target	3 targets	6 targets
FTS-RR	103	178	173	91	109	106	74	95	75
ATRC	96	118	130	86	98	105	75	80	85

Table 3. Comparison of FTS-RR and ATRC: Total Time Steps considering 3 targets

	20 robots			30 robots			40 robots		
	Grid map 30x30	Grid map 50x50	Grid map 60x60	Grid map 30x30	Grid map 50x50	Grid map 60x60	Grid map 30x30	Grid map 50x50	Grid map 60x60

FTS-RR	178	294	434	109	171	284	95	131	203
ATRC	105	230	340	99	190	280	85	153	210

Table 4. Comparison of FTS-RR and ATRC: Average Energy for a Robot in term of units of charge considering 20 robots

	5 targets			7 targets			10 targets		
	Grid map 30x30	Grid map 50x50	Grid map 60x60	Grid map 30x30	Grid map 50x50	Grid map 60x60	Grid map 30x30	Grid map 50x50	Grid map 60x60
FTS-RR	455	689	898	499	729	950	464	805	993
ATRC	625	958	1228	700	999	1155	725	1050	1305

Table 5. Comparison of FTS-RR and ATRC: Average Energy for a Robot in term of units of charge considering 30 robots

	5 targets			7 targets			10 targets		
	Grid map 30x30	Grid map 50x50	Grid map 60x60	Grid map 30x30	Grid map 50x50	Grid map 60x60	Grid map 30x30	Grid map 50x50	Grid map 60x60
FTS-RR	333	581	676	395	689	676	435	791	887
ATRC	510	674	839	540	697	839	557	719	994

5 Conclusions

A brief comparison between two bio-inspired strategy to perform demining task has been proposed. The first approach (FTS-RR) is based on a local communication and it is inspired to FireFly (FF) algorithm whereas the second approach (ATRC) make use of exploring ANTs to know the network topology in order to speed up the completion of demining task. Both techniques can be useful in search and recruiting tasks. However, by simulations it is possible to see as the FF algorithm seems to be more scalable when the convergence time is not so important in comparison with the energy consumption. This technique seems to perform better especially in condition of higher number of robots or higher number of targets especially in terms of energy consumption. On the other hand, ATRC seems to be more performing in terms of task execution because the knowledge of the topology and robots disposition can speed up the recruiting task reducing the overall time to search and recruit. However, simulations show the degradation of ATRC in terms of energy consumption because a protocol and more communication among robots become necessary.

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