Computers and Electrical Engineering 70 (2018) 53–65

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Behavior-based swarm robotic search and rescue using fuzzy controller☆

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ARTICLE INFO

Keywords:
Behavior-based robotics
Swarm robotics
Search and rescue
Fuzzy controller
Virtual leader
Distributed search

ABSTRACT

Search and rescue (SAR) is one of the foremost issues in disaster management. A robust SAR mechanism can significantly reduce the number of causalities. This paper presents a behavior-based model for a swarm of small robots to perform an efficient SAR operation in an unknown environment. The swarm is guided by a dynamically selected virtual leader (VL). A self-contained dynamic goal-seeking mechanism, using behavior-based approach, is designed to search targets (victims). Under the leadership of VL, the proposed model retains the integrity of the swarm while driving it from its current position to referenced goals. Fuzzy logic has been used to design constituent behavioral modules, namely obstacle avoidance, alignment, and inter-robot cohesion. The model has been simulated to validate its efficiency and the findings reveal that robots moving as a swarm are more effective in the SAR process as compared to multiple single robots.

1. Introduction

Multi-robot system (MRS) [1] has inspired remarkable research interest in recent years. MRS has many advantages over model-based complex robots [2]. MRS is more tolerant to faults and failures [1] and exploits the benefits of distributed sensors and actuators system. Therefore, MRS is more useful than model-based robots in applications such as search and rescue (SAR), spatial exploration and coverage, surveillance, transportation, and demining [2].

SAR is a challenging task. To rescue the victims from the debris, SAR teams have a limited time of approximately 48 h. The survival rate decreases drastically afterward [3]. Therefore, it is a time-constrained task and requires, not only the exploration of the arena but also determination of the exact locations of victims without compromising rescuers' safety. In MRS, exploration and localization are challenges, coupled with the requirement to do it with a time constraint.

Exploration is a mapping of an unknown environment to determine its characteristics, whereas coverage is about searching an object of interest in a given map. Exploration and coverage in MRS is achieved by applying control laws inspired from biological principles, adapted from large societies of animals, such as school of fish, flock of birds, ants, and bees etc. In MRS, simple control laws inspired from nature are applied on a large number of relatively simple robots. This field of robotics is called swarm robotics [9]. In SAR, a swarm of autonomous, and low-cost robots perform the task of search and rescue in collaboration.

In MRS, there is no central control mechanism or a leader to give instructions; rather each robot has a simple local controller or a set of behaviors [4]. These robots interact with each other using these local rules or behaviors, and a global system level behavior

☆ Reviews processed and recommended for publication to the editor-in-chief by associate editor Dr. A. Chaudhary.

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https://doi.org/10.1016/j.compeleceng.2018.06.003
Received 30 April 2017; Received in revised form 30 May 2018; Accepted 3 June 2018
0045-7906/

emerges with accomplishing the desired task. In such a distributed collaborative environment, to achieve useful task, a navigation component needs to be designed so that a swarm could explore the environment and follow the desired trajectory. In addition to the fundamental control strategies, relating to the operation of SAR, the mechanism of obstacle avoidance is also required to let the robots move smoothly in the environment. For SAR task, a behavior-based strategy is utilized which considers *next-best-view* across a frontier combined with the mechanism to *avoid past* [5]. This exploration technique is then combined with swarm control dynamics, which includes swarm scaling, dynamic goal seeking, and victim detection.

It is obvious that the environment is only partially observable. The observations come from sensors, actuators, and information shared by the other robots in the neighborhood. In such a partially observable environment, fuzzy logic provides a robust solution in such situations involving incomplete and erroneous data [6].

Various algorithms and techniques have been proposed for searching targets, both for simulated and physical swarms of robots [7]. Most of the techniques are extensions of particle swarm optimization (PSO) algorithm [8] [9]. The inspiration behind the PSO algorithm is the flocking behavior of birds and fish. A survey and comparison of various swarm intelligence-based multi robots searching techniques has been presented in [10]. In the following a review of research work related to this paper is presented.

An extension of PSO towards distributed searching presented by Couceiro et al. [11], which is named as Robotic Darwinian PSO (RDPSO), a population of robots move together in a search space (disastrous region) and search for global optima (e.g. victims). Each robot computes and communicates (within the network it belongs to) its state, which is composed of its position and performance. Another extension of PSO named as extended particle swarm optimization (EPSO) [12] presented by Pugh and Mrtinoliis. This is one of the earliest techniques that could handle real world constraints like obstacle avoidance, and each agent can only communicate within a certain fixed radius. Hereford & Siebold [9] presented a PSO-base search algorithm called physically-embedded particle swarm optimization (pePSO) in which PSO algorithm is embedded into each individual robot, and the robot is considered as a particle. This algorithm could easily be scaled for a large number of robots and targets, effectively with minimum inter-robot communication. Also, a PSO algorithm having improved grouping strategy based on constriction factors has been proposed by [13].

A glowworm behavior inspired algorithm called glowworm swarm optimization (GSO) is presented by Krishnanand et al. [14], which divides the population into subgroups so that subgroups track multiple targets simultaneously. Gazi and Passino [15] proposed aggregation of foraging swarm (AFS), which is modeled based on the principles of attraction/repulsion, similar to the (flocks, herds, and schools) model [16]. In a more recent work [17], a search method for swarm robots has been proposed, in which an indirect information interaction mechanism is used for target search.

Stirling et al [18] proposed an aerial swarm robot-searching technique for indoor environments. Although, the aerial swarm has certain advantages over ground-based robots (e.g. flying above the obstacle/debris and increased speed), there are some problems as well, such as low bandwidth communication, limited on-board processing and sensory capabilities, and limited flight time. In [18], an energy efficient model is presented based on local sensing and local communication. In [19], a detail of project GUARDIANS (group of unmanned assistant robots deployed in aggregative navigation by scent) is presented, which is also swam based. The major role of the swarm robots in this model is to search for human beings in a smoke-filled environment. In [20], a swarm of helicopters is used to search a target in a planer area such as a field. Waharte et al [21] proposed framework of a swarm of unmanned aerial vehicles to find a victim using greedy heuristics, potential-based algorithms, and partially observable Markov decision process. A hybrid approach using aerial and ground robots for searching targets in the urban environment is proposed by [22], where aerial robots are used for coordination between the swarm of ground robots. In [23], a swarm-based search algorithm is proposed, in which four simple laws of mobility based on fuzzy logic were introduced for each robot, subject to its geometric constraints. Venayagamoorthy et al. [24] combined swarm intelligence and fuzzy logic for collective robotic searching task. They proposed two approaches: (1) a canonical PSO algorithm using a fuzzy term to replace a part of the PSO dynamics (a fuzzified swarm of robots), and (2) a swarm of robots using fuzzy controllers (swarm-fuzzy controllers).

Xie et al [25] presented artificial physics optimization (APO) algorithm as a modeling tool for swarm robot-based search algorithm for victim search in disastrous scenarios. A mechanism based on the concept of a virtual force among robots is presented, which gets as force of attraction and repulsion. Performance of the technique proposed in this paper is compared with Xie et al [25].

Most of the above techniques can only works in an environment without obstacles. Many of these algorithms have convergence issues [29]. Some of these algorithms require map and localization while, others require large scale communication. Most of the techniques develop swarms which are leaderless.

This paper deals with a behavior-based model of swarm robotics for search and rescue. A Virtual leader drives the swarm towards unexplored area. The leader is selected dynamically. Simulation is performed to validate the model using a challenging environment. The behavior-based exploration and coverage mechanism presented in [26] is extended towards a swarm-based architecture and the application of fuzzy logic. The salient features of this research work are as follows. 1) A self-contained dynamic goal-seeking mechanism using behavior-based approach has been implemented for searching targets in an unknown environment, 2) bio-inspired dynamic virtual leaders are used, who steer and drive the swarm from current goal to the reference goal and 3) an avoid past behavior has been designed to help goal-seeking behavior more efficiently.

For the sake of organizational convenience, the entire research work has been neatly divided into four sections. Section 1 provides an introduction. Section 2 presents the proposed model of behavior-based swarm robotics using fuzzy data controller. Section 3 outlines the results of the experiments and finally, Section 4 concludes the paper with an outline of potential studies in the future.

2. Behavior-based swarm control architecture

The performance of a swarm largely depends on the local control rules of the individual robots. Each robot of the swarm has an