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MRoCS: A new multi-robot communication system based on passive action recognition

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ABSTRACT

Multi-robot search-and-rescue missions often face major challenges in adverse environments due to the limitations of traditional implicit and explicit communication. This paper proposes a novel multi-robot communication system (MRoCS), which uses a passive action recognition technique that overcomes the shortcomings of traditional models. The proposed MRoCS relies on individual motion, by mimicking the waggle dance of honey bees and thus forming and recognising different patterns accordingly. The system was successfully designed and implemented in simulation and with real robots. Experimental results show that, the pattern recognition process successfully reported high sensitivity with good precision in all cases for three different patterns thus corroborating our hypothesis.

1. Introduction

Search-and-rescue (SaR) missions using a multi-robot-system (MRS) are considered to be very challenging as communication amongst robots is limited due to the fact that the environment is often prone to sensory noise with limited information. Examples of SaR scenarios include earthquakes, floods or other natural disasters and multi-robot-systems could help in the task of rescuing people by aiding fire brigades, ambulances, police forces, and volunteers [1].

A MRS consists of a number of intelligent, self-organised and collaborative robots. Multiple robots can perform complex tasks with a minimum time span and can increase their robustness in the environment [2]. In MRS, individual robots are smart enough to make decisions and can plan to accomplish a complex task collectively. They rely on mutual interactions, as well as the local information from the environment, where the loss of a given robot does not affect the overall system.

In a swarm, robots dynamically assign themselves to different tasks to fulfil the requirements in a particular environment and conditions [3]. Nevertheless, with the increase of number of robots, as it typically occurs in a swarm of robots, coordination and communication are necessary to fulfil complex tasks. Communication has a huge impact on the performance of a swarm, where the robots interact with each other to exchange knowledge about their environment [4]. However, in such dynamically changing environment, traditional robot communication often reaches its bottleneck and there may be uncertainty on account of incorrect information or information not reaching the robots within the swarm.

Robot communication can be divided into three categories, (1) explicit communication (robots directly and intentionally communicate the relevant information to their teammates through some active means) [5–8], (2) implicit communication (robots sense the effects of their teammates' actions through the influence they leave on the environment *e.g.,* stigmergy) [9,10], and (3) passive action recognition (robots use sensors to directly observe the actions of their teammates).

Explicit communication has been the one widely used due to its directness and ease with which robots become aware of the actions and/or goals of their teammates [11]. However, explicit communication shows limitations in terms of fault-tolerance and reliability, as it typically depends upon a noisy, limited-bandwidth communication channel that may be unable to continually maintain all members of the robot swarm connected.

On the other hand, implicit communication is non-transient and needs no encoding or decoding, knowledge of place, or memory. Robots only react to the local configuration of the environment [12]. However, with the increase in number of robots, the interactions also increase, which decrease the response time. As a

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result, robots are unable to achieve given tasks [13]. Additionally, the robots, which have no knowledge to detect if whether or not the task has been completed, may jeopardise the objectives of the entire swarm.

For instance, let us consider a military applications, wherein robots need to exchange messages. An explicit communication is vulnerable as it can be intercepted, or understood, by opposing forces. From a security perspective, any open implicit or explicit communication method can be jammed, intercepted or otherwise disturbed relatively easily by the enemy. The security of wireless communication has been well researched, but the security of unconventional and more exotic interaction methods should be explored and presents a compelling security challenge [14]. Therefore, other types of communication, such as passive action recognition, is useful and not easily interpretable. Shim and Arkin [15] advocated that a biologically inspired behaviour as a robotic deception system for military application can lead to a robust passive action recognition based communication, which can be beneficial to improve the security system.

Passive action recognition techniques do not rely on any communication medium, language or environmental configuration [16]. However, for such communications to be successful, robots need to be able to recognise teammates' behaviours by decoding and interpreting their actions [17]. Hence, in addition to military applications, this is also useful for hazardous environment, such as, in case of a natural disaster, where establishing communication channel is challenging and sometimes impossible. Human–robot interaction can also be made easy by passive communication, especially when humans are not connected to any other traditional robot communication medium. This type of swarm behaviour can be observed in nature *e.g.,* honey bees' waggle dance [18,19] which was used as a bio-inspiration in this work.

Honey bees daily life cycle involves collection of good nest or searching for nectar in neighbouring environment. Although the individual insect has limited ability, collectively they can perform complex tasks using their self-organising behaviour without any recognised interaction between them. The nest or nectar collection activity can be expressed in following four categories: (i) Scouting/foraging; (ii) Pattern formation; (iii) Pattern recognition; and (iv) Decision making behaviour. Recently, roboticists have shown keen interest on developing new models inspired by the honeybee waggle dance due to its ability for passive communication, which helps to improve adaptive robotic behaviour and avoids complex multi-point (wireless) communication among robots [20].

In this paper, we are particularly interested in mimicking honeybees' waggle dance as a form of passive action recognition within MRS. Although there are a number of papers available in the literature that explain the pattern formation [21,22] and pattern recognition behaviour [23] of honey bee waggle dance, to the best of authors' knowledge, its application in robot communication is largely unexplored. The proposed approach considers the design of a multi robot system, where a scouting (leading) robot generates a behavioural pattern by body movement [24] while follower robots recognise and decode the pattern without the need to implicitly or explicitly exchange information among themselves. The main contributions of this paper are threefold:

1. Mimicking honey bees' waggle dance in multi-robot system which includes,
   - Simple and complex *pattern formation* resembling scouting/foraging behaviour and
   - *Pattern recognition* by observing and recognising previously formed patterns (a behaviour of follower bees).
2. Simulating our proposed system using Robot Operating System (ROS).[1]
3. Prototyping the MRS using a group of Unmanned Aerial Vehicles (UAV) (*i.e.,* Parrot AR. Drones[2]).

The paper is organised as follows: background and related work are described in Section 2. Details of the overall system and experimental set up are discussed in Section 3 following the methodology on pattern formation and pattern recognition in Section 4. Results obtained from simulations and real environment are reported and discussed in Section 5 followed by concluding remarks and future work in Section 7.

2. Background and related work

Swarm intelligence and biologically inspired computation, especially in robotic applications, have gained significant attraction from researchers in recent years [25]. Many systems have been proposed in the literature that mimic the collective behaviour of insects or animals to perform complex tasks using a group of simple robots (often referred as agents). Many bio-inspired algorithms, such as ant colony algorithm, firefly algorithm, bee algorithm and particle swarm optimisation have been applied in various areas of science and engineering research [26–28]. Communication in a swarm is extremely important because, robots must share their information to achieve a task. Increasing the number of robots in a MRS decreases the amount of time needed to complete a given task. However, this may not be always true in a practical scenario as multiple robots struggle to speed up the task due to limited communication bandwidth. As a result, the performance of the system degrades as more robots are employed. Thus, we need a good communication system to flow the information uninterruptedly. In this section, we shall discuss about various types of communication proposed in the literature and used in MRS, followed by an overview of honeybees' life-cycle and waggle dance in the context of this paper.

2.1. Multi-robot communications

The term robotics consists of sensing information from the environment, understanding the main features, modifying them with their requirements and then acting on the environment. The main objective in MRS is to achieve the final goal through inter-robot interactions. To achieve this goal, robots require information about their teammates and the environments. According to Parker [4], this information can be acquired by three common techniques: (a) explicit communication, (b) implicit communication and (c) passive action recognition.

2.1.1. Explicit communication

Explicit communication is based on the intentionally transmitting and receiving information via some type of protocol or language as a medium. This is always intentional and the robots are completely aware of it. An example is human's interaction with each other using spoken languages. Deploying this type of communication in MRS always requires some medium, *e.g.,* radio, Ethernet or wireless. However, the communication medium cannot always be shared, therefore it is necessary for the robots to obtain exclusive access to them. The problem of communication medium sharing is often associated with bandwidth limitation. Rekleitis et al. [29] examined the problem of multi-robot coverage path planning for a team of robots with limited communication, where the robots operate under the restriction that communication between two robots is only available when they are within the line of sight of each other. In comparison, explicit communication is less

1 http://www.ros.org/.

2 http://ardrone2.parrot.com/.