Chapter 25
A Distributed Framework and Consensus Middle-Ware for Human Swarm Interaction

Ghazaleh Pour Sadrollah
Monash University, Australia

Jan Carlo Barca
Monash University, Australia

Jens Eliasson
Luleå University of Technology, Sweden

Asad I. Khan
Monash University, Australia

ABSTRACT

A swarm of robots can perform a variety of missions that are time critical, cost sensitive, and too complicated for a single individual to undertake. In this context, the ability to design robust, scalable and flexible collective behaviours, for the coordination of large numbers of robots to complete particular tasks specified by a human operator, is crucial. For human swarm interaction, it is critical for the robots to be able to continuously achieve swarm's consent to perform tasks specified by a human operator in a dynamically changing environment. Furthermore, an appropriate quorum threshold should be defined as a variable determining the system's behaviour, which is beneficial in environments where stable connectivity might be an issue. These challenges therefore justify this research into designing a group decision-making process such as consensus algorithm for managing swarms of flying robots by considering various circumstances including battery limitations of the robots, possible node failures, and utilising appropriate sensory vision distance.

INTRODUCTION

Swarm Robotics (SR) and Human-Swarm Interaction (HSI) has drawn growing attention in recent years (Barca & Sekercioglu, 2013; Green & EBSCOhost, 2014; Mi & Yang, 2013). The term "swarm" refers to a large population of locally interacting individuals with shared goals. It is used to describe all forms of communal behavior even though it brings up associations to coordinated movement in space. A swarm of robots can perform a variety of missions that are time critical, cost sensitive or too complicated for a single individual to undertake. The set of actions that a swarm of robots can perform is furthermore much larger and more complex in comparison to a single robot (Navarro & Matía, 2012).

In HSI a human operator is given an opportunity to interact with the SR system to ensure that desired tasks are carried out in a reliable and efficient manner. This is of critical importance if SR technologies are to be employed in real world situations where rigid standards must be met. In this context, it is important that the human and the robots are able to interact effectively, thereby allowing the human-swarm symbiosis to fully exploit their combined skills (Şahin, 2005).

To address this issue, there is a need to set up a wireless communication link between a human operator and swarms of robots via a base station. Internet of Things (IoT) technology can be used to alleviate this challenge, however, since IoT mostly has been used in stationary devices, using it in elastic and dynamic robot swarms will introduce new challenges, which need to be addressed. It is particularly important that the resulting technology satisfies potentially severe energy and weight constraints, while facilitating robust connectivity.

We employ lightweight and low-power Mulle platforms to tackle these issues as Mulle can be used as a sensor and actuator platform, which supports wireless communication in IoT applications (Eistec, 2014). The version of Mulle that has been used in this research is running the Contiki operating system, which gives us the benefits of support for different sensors, communication protocols, low power networks, security mechanisms, and other important sub systems. Additionally, it can extend IP based communication over several kilometers in line of sight (approx. 0.5 to 1km under normal operation and more than 1km when operating within line of sight).

In addition we propose agreement mechanisms that can propagate control commands and associated quorum values through swarms of robots in a distributed fashion (Parker & Zhang, 2004). This ensures that human operators can interact with the swarm in a manner that does not violate the principles of SR and requires minimal bandwidth, which is beneficial in environments where stable connectivity cannot be guaranteed. The proposed agreement mechanisms are of utmost importance as the system itself can fragment as a result of different members choosing different solutions. If such a split occurs, the functionality of the swarm could be lost, which could then result in non-completion of desirable missions.

There are two levels of communication in the proposed system. One is between the human operator and the swarm in which actions and associated quorum values are sent from the base station to the swarm. The swarm then agrees on the quorum value and executes the action if the numbers of robots that agree on the task are equal or greater than the quorum value specified by the human operator. For human-swarm communication, the leadership pattern is dynamic and information can be transferred directly to different robots based on their distance to the base. The transfer mechanism is made robust towards leadership failure or inaccessibility via selection of "alternative parents".

The second level of communication is within the swarm where the robots interact without any interference from the human operator. This level of communication is required when the swarm must agree on a value in urgent scenarios that are out of control of the human operator. Intra swarm agreement is

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