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# Swarm behavior control of mobile multi-robots with wireless sensor networks

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ABSTRACT

A swarm is a "complex adaptive system", which is decentralized and self-organized and whose individuals are simple, homogeneous and autonomous. Swarm intelligence is defined to describe its emergent behaviors. Both wireless sensor networks and mobile multi-robots demonstrate swarm features. This paper first discusses the challenges of combining wireless sensor networks and mobile multi-robots, and then proposes a layered dual-swarm framework with three communication channels that can inherit traditional swarm technology while building an efficient interaction channel for both swarms to cooperate. In order to improve the system controllability, a new type of numerical entity called "virtual entity" and related control strategies are introduced. Finally, proof-of-concept implementations are presented and illustrated with simulation scenarios and a physical testbed. The experimental results show that the WSN-MMR swarm system can emerge successfully and robustly from swarm intelligence.



## 1. Introduction

Wireless sensor network (WSN) nodes can closely sense their surroundings in a convenient and distributed way so that they can be considered as nerve terminals connected to a network such as the Internet. Recently, due to their great application potential, a trend has emerged that combines wireless sensor networks (WSN) and multi-mobile robots (MMR) (Arampatzis and Manesis, 2005). Interesting applications can be found in disaster emergency response, military, communication, transportation, and factory automation. With the support of WSN, a mobile robot can extend its sensing limit, coordinate and interact with other partners. For example, in road traffic control, with the support of intelligent road information, based on wireless sensor networks, autonomous vehicles can be induced to choose suitable pathways and behaviors. At dock yards, a wireless sensor network can be used to support smart equipment (mobile robots) to automatically manage distributed resources and optimally schedule their tasks in real-time.

Among various approaches proposed in the literature, there are three main kinds of combinations of WSN and MMR:

(1) WSN–MMR. In this system, mobile robots can be used to spread and maintain the nodes of WSN (Mei et al., 2007; Sheu et al., 2008). With the support of WSN, robots can more effectively navigate in an unknown environment. The Pursuit Evasion Game (PEG) problem can be solved with global search and pursuit on evaders (Sinopoli et al., 2003).
(2) Mobile sensor networks. The nodes have mobility just as mobile robots and the network is self-organized just as WSN. The system can work more actively than WSN with static nodes (Low et al., 2006; Kwok and Martinez, 2008).
(3) Wireless sensor and actuator networks (WSAN). In these kinds of networks, sensor nodes and actuator nodes communicate at the same network level. They cooperate with each other to sense and respond to events in their surrounding environments (Akyildiz and Kasimoglu, 2004; Melodia et al., 2007).

This paper presents a new approach of combining WSN and MMR and discusses the cooperation and constraints between WSN and MMR from the viewpoint of a collective intelligence pattern called swarm intelligence. A layered framework is proposed to keep these two swarms (i.e., WSN and MMR) independent and a communication channel is built to exchange necessary information for possible cooperation between WSN and MMR. To meet the requirements of swarm intelligence control, a novel numerical entity called "virtual entity" is introduced to induce and control the behaviors of the mobile robot swarm through wireless sensor networks.

The remainder of this paper is organized as follows: Section 2 reviews recent work related to swarm intelligence, WSN and MMR; Section 3 compares the swarm features of WSN and MMR; Section 4 is dedicated to the discussion of challenges for organizing and controlling the dual-swarm system composed of WSN and MMR;

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