Advanced swarm robots addressing innovative tasks such as assembly, search, rescue, mapping, communication, aerial and other original applications

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Abstract

Purpose – The purpose of this paper is to review some of the various worldwide projects to develop and apply innovative swarm-type robots to many challenging applications.

Design/methodology/approach – An in-depth review of published information and interviews with researchers and developers of swarm robot technology were conducted.

Findings – Swarm robots continue to be developed to match an ever-increasing number of interesting and innovative applications.

Practical implications – Readers may be very surprised at the tasks that autonomous swarm robots can address and the developments that are underway to further extend the abilities of swarm robots.

Originality/value – This paper is a review of a wide range of the latest swarm robot developments, innovations and applications.

Keywords Swarm robots, Search and rescue, Assembly, Mapping, Communication, Aerial

Paper type General review

Swarm robots are a relatively new technology in the robot field. Traditionally, robots have addressed their assigned application as a stand-alone directed or programmed worker. Over time, they have become more and more autonomous, meaning they operate by making many of the task decisions on their own. For example, today some unmanned vehicles, such as aircrafts, are given a search and find command, and the robot using its onboard sensors and computing ability creates its direction commands including take off, return home and landing without operator intervention.

Swarm robots continue this self-directed ability but combine it with the ability to work together with other identical robots to accomplish a common task such as assembly of an object, search and rescue operations or other tasks where "multiple hands" are needed to complete the assignment.

Some of the development challenges include how to build small but able robots and how to get the team of robots to work together effectively while operating independently. The development task is often described as how to get the swarm robots to function like an army of ants. Many organizations have been researching and developing technologies important to swarm robots.

While the concept is receiving a lot of attention currently, the idea has been present for a number years; an early developer of swarm robots was iRobot Corp., a half–a-billion dollar (USD) multi-product organization addressing a wide range of robot types and applications. They are famous for the Roomba home vacuum robot, the Scooba floor washer and a telepresence robot, as well as many military robots including unmanned ground robots.

Several years ago, iRobot developed a family of swarm robots as part of a Defense Department Research Program (DARPA) contract that can establish a wireless network and/or provide everywhere eyes or serve as a pocket-sized tank (Figure 1). The concept was patterned after insects. The user did not need to communicate with each and every robot but could command one robot with the task and that robot would communicate with all the other robots in the swarm and they would jointly complete the task.

Research projects

James McLurkin at Massachusetts Institute of Technology and Daniel Yamins at Harvard (McLurkin and Yamins, 2005) have developed algorithms for assigning swarms of robots to subgroups to address specific global task distribution. One algorithm compiles an inventory of all robots and places it on each robot. Another algorithm assigns tasks to individual robots. A third algorithm balances communication and running time on the robots.

Another project of Professor McLurkin, while at Rice University, has been to develop software to better enable swarms of robots in the 10-10,000 count range to effectively

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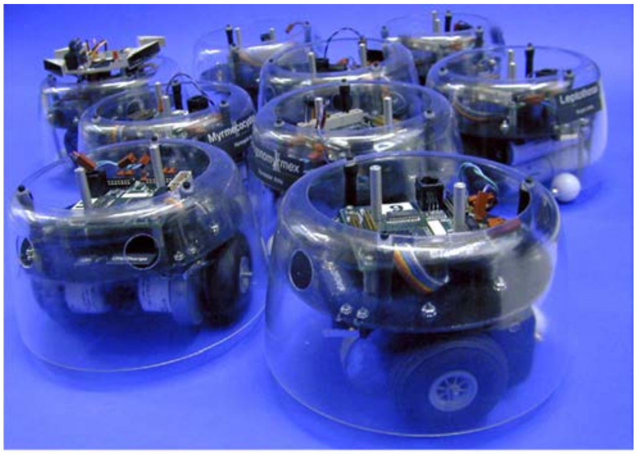
Figure 1 Group of one of the several SwarmBots developed under the DARPA contract by iRobot



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communicate individually while maintaining distributed control. He has examined the behavior of large groups of insects for insight in to swarms. More of this project can be followed at www.people.csail.mit.edu/jamesm/swarm.php

Researchers at the University of Colorado Boulder have developed a robotic building block as the starting point for reproducing large quantities of swarm robots for complex systems. One project has been to create robots the size of ping-pong balls (about 2.5 cm in diameter) which they have called "droplets" (Figure 2).

The project is to demonstrate how such swarms can self-assemble devices in space, as well as provide swarm intelligence such as pattern recognition, sensor-based motion and adaptive shape change (Cornell and Tanner, 2014).

A project at Bristol Robotics Laboratory has focused on developing an ultrasonic position tracking system for studying

Figure 2 Swarm robots at the University of Colorado called the "droplet", each about 2.5 cm in diameter. One to the right has the cover off, showing the internal features such as the electronics circuit board

Source: © Casey A. Cass/University of Colorado, used with permission

swarm robot behavior. Ultrasonic tracking is seen as an improvement over video tracking. The need for clear images is no longer a requirement. Operations can be conducted even in total darkness.

The Harvard University School of Engineering and the Wyss Institute for Biologically Inspired Engineering have developed a number of swarm-type robots. (Wyss Institute, 2014) Their TERMES robot is a swarm program inspired by studying termite mounds (Figure 3). TERMES robots can build towers, castles and pyramids out of foam blocks, autonomously building themselves stairs to reach high levels and adding bricks where they are needed.

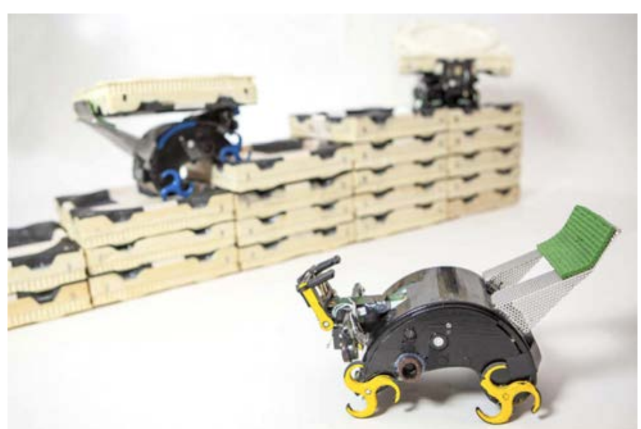
Another swarm program known as the RoboBees project is building on the research understanding developed creating an artificial intelligence-type robot, now known as the Kilobot. For more information on the Harvard/Wyss efforts, visit http://seas.harvard.edu and http://wyss.harvard.edu. To watch a video of the TERMES in action, visit http://youtu.be/LFwk303p0zY (accessed on 02/07/14).

Researchers at the Nanorobotics Laboratory in Montreal, Canada, are working on applying miniature swarm robots to fight pathogens within the human body. One goal is to apply small magnetic robots as an insertion tool into the body to fight cancer. Another project is addressing ways in which to apply swarm robots to perform diagnosis at an early stage in a disease cycle to signal the threat of it becoming life threatening. The technique might reduce the need for more invasive diagnosis techniques.

Another project at Nanorobotics is to apply swarm robot technology to non-invasive surgery. Miniature swarm robots would be placed in the patient's body, and they would work together to perform the needed surgery. The chance for infection might be reduced, and the recovery time would be greatly reduced.

At the Swarm Robotics Laboratory at the Monash University in Melbourne, Australia, work is under way to develop techniques to apply swarm robots to disaster site search and rescue operations, mine clearing and exploration, mapping and dynamic motion capture for the motion picture film industry. Researchers at Monash are concerned that the

Figure 3 The TERMES swarm robots in action, building a stairway



Source: © Eliza Grinnell, Harvard School of Engineering and Applied Sciences, used with permission research on swarm robots be applied primarily for the betterment of mankind and not just for military applications. Flying swarm robots are the goal of a project at the Laboratory of Intelligent Systems, Ecole Polytechnique Federale de Lausanne (EPFL) in Switzerland. (LIS, 2014) Researchers there are developing technology to enable a Swarming Micro Air Vehicle Network (SMAVNET) to rapidly create a communications network to facilitate an effective communications for the disaster relief team.

The micro air vehicle (MAV) or flying swarm robot family they have developed is built out of expanded polypropylene and weighs just 420 g (Figure 4). The craft has a wingspan of 80 cm. An electric motor to power the propeller is mounted at the back of the flying wing. Control surfaces include elevens (combined ailerons and elevators). The energy source is a lithium polymer battery that provides for 30 minutes of flying time.

The craft is controlled by an autopilot for altitude, airspeed and turn rate, while an embedded micro-controller uses information from all the sensors which are on the platform. The autopilot operates on a Gumstix Overo CPU board running the Linux. A USB Wi-Fi dongle transmits the flight trajectories. Also onboard are a u-blox LEA-5H GPS module and a ZigBee (XBee Pro) transmitter.

The robots communicate which each other using wireless communications. As the swarm robots are deployed one at a time, they hold position, and the remaining robots move ahead to complete the communication network. The robots are autonomous, but they can be monitored and controlled if needed through a swarm interface running on a single PC.

Some other swarm robot projects are also not earth bound. At the University of Karlsruhe, a project is underway (the European Union-funded I-Swarm Project 31018) to develop a centimeter-scale swarm robot which might one day help colonize the planet Mars. The goal is to develop a team of swarm robots that will function much like a colony of ants. The benefit is that the swarm robots can function in a mission, where a high degree of redundancy is required such as on space missions. If one robot is damaged or fails, the mission can continue with the other robots stepping into and taking over the task and completing the assignment.

Figure 4 A swarm of Swarming Micro Air Vehicles ready to take off for an airborne mission

Source: © Laboratory of Intelligent Systems – EPFL, used with permission

Key to the effectiveness of the I-Swarm approach is their ability to collaborate and communicate using an infrared light technology. Each robot receives and then rebroadcasts when signaled to communicate. The I-Swarm robot "brain" is on a flexible printed circuit board that is folded in a shape that project team member Marc Szymanski describes as in the shape of an origami. The robots vary in scale and design. One group of wheeled battery-powered robots are the size of a two-euro coin and are known by the name Jasmine robots. The smallest robots are but 3-mm long and move by vibration. The robots carry 8 KB of program memory and 2 KB of RAM storage. For more information, see videos of the I-Swarm robots in action.

The European Commission has funded a multi-institute project known as SWARMONOID Project 11084 to develop a trio of swarm robots, a Foot-Bot, a Hand-Bots and Eye-Bots. (SWARMANOID, 2011) The researchers are located in Belgium, Switzerland and Italy, and are developing this family of heterogeneous, autonomous and dynamically connected robots.

The Foot-Bot is 17 cm in diameter and 29-cm tall. Based on the marXbot platform, it includes a CPU and vision module, a distance scanner, range and bearing modules, a self-assembling module and a mobility and battery module.

The Hand-Bot has two hands or grippers with 8 df. The robots are well suited to climbing vertical surfaces, as well as manipulating objects while not having the ability to move on horizontal surfaces. The unit is 38 × 44 × 30 cm^3. Vertical mobility is provided by a rope that is magnetically attached to the ceiling. Control is by the same CPU as the Foot-Bot.

The Eye-Bot has eight rotors, arranged in a coaxial quad-rotor configuration. The rugged lightweight unit is 50 cm in diameter. A ceiling attachment device enables the unit to acquire a bird's eye view of the environment. A custom pan-tilt camera system provides 360-degree vision. Also provided are a 360-degree infrared distance sensor and a three-dimensional position sensor. Other sensors include a 6-df sensor and a magnetometer, as well as sonar and differential pressure sensors.

Swiss AI Lab IDSIA (Istituto Dalle Molle di Studi sull'Intelligenza Artificiale) has focused on a number of technologies important to swarm robotics. (IDSIA, 2014) One area of research has been to investigate the symbiotic human – swarm interaction, an important aspect of how humans can effectively give commands to a team of swarm robots. The goal is to develop a robust means to transmit the commands and for the swarm robots to collectively achieve a consensus of the meaning of the gesture.

Efforts at IDSIA are focusing on studying multi-robot navigation and obstacle avoidance in a cultured and dynamic workplace. They are also addressing better understanding of how to reduce evaluation time of trade-offs concerning robot speed and adaptation to being robust.

Research at the Universite Libre de Bruxelles and the Instituto Universitario de Lisboa is addressing the understanding of spatially targeted communication and self-assembly of swarm robots carrying wireless communications abilities, as well as those carrying high-definition cameras (Mathews *et al.*, 2012). Their goal is to find means to improve the ability of humans to manage such swarm activity. A video of their efforts is available at: http://youtu.be/i3ernrkZ91E

Commercially available swarm robots

Commercialization is coming slowly to swarm robots. While the tasks swarm robots can address grow almost daily, commercialization is not moving forward as rapidly. Relatively few companies offer products for sale. For a presentation about the Kilobot see Rubenstein *et al.* (2012).

The K-Team now produces the Kilobot swarm-type robot developed at the Harvard University (Figure 5). The Kilobot is a low-cost (only about US$14 each) robot only 33 mm in diameter with many features including:

- small, only 33 mm in diameter;
- motor control with 255 power levels;

Figure 5 Kilobot robot with power recharge contacts visible front center right and on the left of the robot

Source: © K-Team Corp., used with permission

- can communicate with neighboring swarm robots to 7 cm;
- neighbor-to-neighbor distance sensing;
- ambient light sensing; and
- rechargeable battery power.

The swarm can be controlled and programmed en masse with an infrared controller. Battery recharge is simple, just move the Kilobot in between a pair of conductive surfaces.

Another robot available from K-Team is the Khepera robot developed at the LAMI Laboratory at EPFL in Lausanne, Switzerland (Figure 6). It is 5.5 cm in diameter and 30-mm high. It offers a speed of 0.02-1.0 m/s. It has a mission time of up to 45 minutes. Options include a gripper, cameras and two-way radio communications.

For further information on the K-Team Kilobot swarm robot and to watch video, visit www.k-team.com/mobile-robotics-products/kilobot/introduction

Figure 6 Khepera robot

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Other swarm developments

An organization known as Swarm Systems Ltd. developed a micro-sized flying robot family known as the OWLS's. It was a light-weight quad-rotor helicopter-style craft. The craft could perform most aerial maneuvers as well as hover. The craft was designed to operate outdoors in up to moderate wind conditions.

Basic assignment directions were transmitted from a laptop computer. But onboard capability enabled the crafts to continue their swarm assignment even if communication with the laptop was lost during the mission. Early applications took the form of urban reconnaissance.

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