

Impact Objectives

- Develop a framework for controlling groups of intelligent air and land robots
- Explore a range of applications for robot fleets based on a new decentralised method of controlling robot worker swarms



Efficient control systems for robot fleets

Associate Professor Yasushi Kambayashi and Professor Munehiro Takimoto discuss the focus of their work, a new and more efficient way to control intelligent groups or swarms of robots, to assist in a variety of tasks from search and rescue to transporting large objects



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inter-robot movements of the mobile agents contributes to the flexible and efficient use of the robot resources. A mobile agent can migrate to the robot that is the most conveniently located to a given task.

Within this research programme you are working on three applied projects, can you outline what these are?

MT: One is formation control of multiple flying robots that inspect structures such as bridges. Another is the detection and capturing of intruders by multiple mobile robots in indoor environments. These two are extensions of our formation control project, and both are based on multiple mobile software agents. The other is an evacuation support system that provides evacuation routes in case of disasters. When communication base stations break down due to disasters, it may become difficult for people to use their smartphones connected to the Internet. We are addressing this problem by using multiple kinds of mobile agents in addition to static agents on smartphones that use a mobile ad hoc network. The system collects information with mobile agents and diffuses information via mobile agents so that the system is able to provide an optimised evacuation route for each user in a dynamically changing disaster environment.

What are the main challenges from this work and is there a project you are particularly pleased with?

MT: The main challenge is constructing practical robust physical robots for each project. Since I am not a hardware person, I rely on some mechanical engineering contributions. The evacuation support system has attracted much attention in the research community. This application of mobile software agents may become the next main topic of our research.

What is the ultimate impact of this work?

YK: Our purpose is to construct a framework for super-distributed systems that are robust, flexible and economic. Since none of the systems we are proposing use any central controller, they can continue to operate even if some of the mobile robots break down. Since mobile agents can deliver knowledge and new features, we can add and introduce new functionalities while the system is running. The mobile software agents can also migrate from one robot to another instantly with almost no cost, therefore our agent-based systems can reduce energy consumption compared to a system consisting of only physical mobile robots. ▶

Can you explain what your work with control systems and robots is hoping to achieve?

YK: Since 2004, we have engaged with multi-robot systems based on mobile software agent systems. My team and I have proposed a framework for controlling multiple intelligent robots in groups using what we call higher-order mobile agents. This framework will help users to construct intelligent robot control software using these migrating mobile agents. Since the migrating agents are higher-order, the control software can be hierarchically assembled in real time. Dynamically extending control software by the migration of mobile agents enables the mobile agents to make robot base control software relatively simple, and adds functionality as knowledge of the working environment increases. The model of our system is a fleet of cooperative multiple mobile agents executing tasks by controlling a pool of multiple robots. The property of

Designing robot swarms

A new decentralised method of controlling swarms of robot workers mimics the coordinated behaviour of ants; drastically reducing the power needed to employ these systems while maintaining performance and coordination

Automation of tasks using robots is a rapidly evolving process. While the robots taking over work have mostly been large, single purpose machines designed to carry out one or two functions, there is a growing demand for smaller, lighter and more flexible robots. These machines are being built to work as cooperative swarms or fleets. In this way they can be distributed in an environment and through communication networks maintain contact and coordinated function. This flexibility and small size means they can replace humans when tasks are either too dangerous or physically impossible for a person to complete.

The hardware side of this technology is largely in place. Drones are already commonplace and getting smaller and more efficient all the time. However, the challenge now is how best to coordinate the movements of multiple robots remotely, explains Professor Yasushi Kambayashi, who is based at the Department of Computer and Information Engineering, Nippon Institute of Technology in Japan. 'Until recently the standard was to relay information and instructions from a central base out to each robot,' he outlines. 'The robots communicate with each other but data is being transmitted back to the central base in a hierarchical way via nodes placed out in the environment that relay the signal to each robot and back.' This means every robot must have a full set of instructions and requires multiple nodes as the robots

increase their distance from home base and each other. This design consumes a lot of energy. 'The nodes and central base must eventually handle all information from the system and therefore burn out, necessitating constant recharging.' A new, decentralised control system is now being developed by Kambayashi and a team of researchers, who take inspiration from social insects like ants.

INSPIRED BY INSECTS

The crux of this new control system is mobile software agents. These mobile agents are packages of computer software and data that can autonomously migrate from one computer to another via communication networks and continue their designated program on the new device. Think of these mobile agents as messengers or pilots that can jump from one robot to another and seamlessly continue their work once in the new machine. In this way each robot is an empty vessel waiting to be inhabited with a new pilot and sets of instructions. 'Mobile software agents are autonomous objects that can migrate from one robot to another through a communication network and can deliver control programs as they are needed,' highlights Kambayashi. 'The migration property of the mobile agents introduces the flexibility and efficiency in the use of the robot resources in multiple robot systems. A mobile agent can migrate to a robot that is the closest in the field for a given task and since the agent movement

is more economical than physically moving a robot it provides significant savings to power consumption.' In essence, a message can move faster than a robot. Furthermore, in a situation where large groups of robots are working and controlled by multiple mobile agents, the agents can be designed to choose idle robots rather than busy ones. Again, resulting in more efficient use of robot resources and adding to the power saving effect.

From the very beginning of the project, Kambayashi has worked with Professor Munehiro Takimoto from Tokyo University of Science. They are working with a number of collaborators, including PhD candidate Shohei Taga from Tokyo University of Science and Tadashi Shoji from Cygames,



Two robots are climbing a hill together

Mobile software agents are autonomous objects that can migrate from one robot to another through a communication network and can deliver control programs as they are needed

Inc, as well as many graduate and undergraduate student from both Nippon Institute of Technology and Tokyo University of Science.

The team considers there are many practical applications for this technology and designed it with swarms of mobile flying robots in mind. These robots can carry out a range of tasks, including infrastructure inspection and assessing disaster sites, where they can fly in tight coordinated patterns to scan every inch of an area. They have taken inspiration from nature for this project, designing their swarm robot system to mimic flocks of birds and leafcutter ants. 'A leafcutter ant is a typical social insect and uses pheromones for communication,' says Takimoto. 'In our robot control system, we have implemented ants and pheromones as mobile software agents.'

In this system, the mobile software agents that drive the robots are the ant agents, and the other agents that provide communication between robots are pheromone agents. The ant agents drive the robots to locations specified by the pheromone agents just like ants in nature follow the pheromone cues laid out by fellow colony members. No one ant has all of the information and there is no need for either a central control or an agent that has the entire set of instructions. 'In order to diffuse the partial information among the neighbouring robots, each ant agent generates pheromone agents and dispatches them to the surrounding robots,' he confirms.

REAL-WORLD APPLICATION

'This work is not basic research and these control systems and robot fleets will have

direct real-world applications,' highlights Kambayashi. Currently, the work is divided into three projects. The first is infrastructure inspection using formations of flying robots. In a related project the goal is to have the robots detect and even capture intruders in an indoor environment. 'These two applications are extensions of our formation control project, and both are based on multiple mobile software agents,' he explains.

Right now, one of the main challenges faced by Kambayashi and his team is building the actual robots. They are looking for collaborations with mechanical engineers because they are very much trained on the software side and are looking for the expertise to support their work. 'The main challenge is constructing practical robust physical mobile robots for all the projects,' says Takimoto. 'The algorithm though has been completely designed and tested in simulations with great results.' Constructing a complete fleet of physical flying robots is now the next step.

LIFE-SAVING ROBOTS

The group's third project is slightly different in that it doesn't require robots, but still capitalises on mobile software agents and it too is receiving lots of attention in the research community. The goal is an evacuation support system that provides unique evacuation routes for individuals trapped in a potential disaster scene. In a disaster scenario a trapped individual may attempt to use their smartphones to get information or directions to a safe location. However, it is likely that in a disaster any communication via a central Internet server will be severed. Kambayashi believes a system of static agents installed on phones

that communicate with multiple kinds of mobile elements on a mobile ad hoc network is the solution. 'The system collects information with mobile agents and diffuses information via mobile agents so that the system is able to provide an optimised evacuation route for each user in a dynamically changing disaster environment,' he outlines.

'Our idea of implementing pheromones as mobile software agents is, I believe, the first such attempt in the mobile multi-robot research community,' enthuses Kambayashi. It is this kind of inspired-by-nature thinking that can help push the use of swarm robots into the mainstream. ●

Project Insights

FUNDING

- Japan Society for Promotion of Science (JSPS), with the basic research program (C) Grant-in-Aid for Scientific Research (KAKENHI), Grant Numbers 20510141, 26350456, 17K01304 and 20K05010
- Suzuki Foundation

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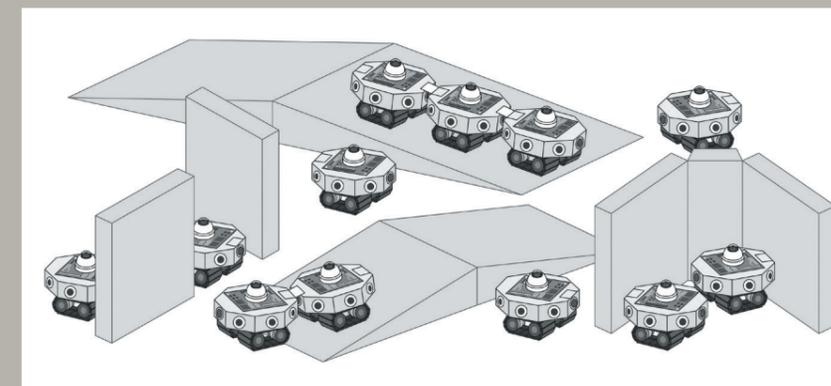
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BIO

Associate Professor Yasushi Kambayashi is based at Nippon Institute of Technology. He previously worked at Mitsubishi Research Institute. Kambayashi received his MSc and PhD in Computer Science from the University of Washington and the University of Toledo, respectively. His research interests include multi-agent systems.

Professor Munehiro Takimoto is based in the Department of Information and Sciences, Tokyo University of Science. He received his PhD, MSc and BA in Engineering from Keio University. His research interests include theory and practice of programming languages, and components derived from them, which include mobile agent systems.



The expected complete system for search and rescue