Bio-inspired algorithms to produce collaborative behaviors for robot teams

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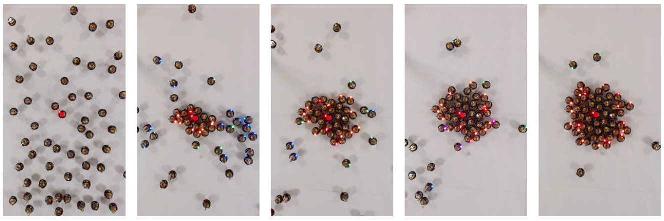

Image showing the kilobots surrounding a target. Credit: Shirazi & Jin.

Researchers at the University of Surrey have recently developed self-organizing algorithms inspired by biological morphogenesis that can generate formations for multi-robot teams, adapting to the environment they are moving in. Their recent study, featured in IEEE Transactions on Cognitive and Developmental Systems, was partly funded by the European Commission's FP7 program.

"This research can be traced back to my previous work on morphogenetic robotics that applies genetic and cellular principles underlying biological morphogenesis to the self-organization of collective systems, such as robot swarms," Professor Yaochu Jin, a Surrey University Distinguished Chair and principal investigator on the study, told TechXplore. "Our main idea was to build a metaphor between cells in multi-cellular organisms and robots, including modules for reconfigurable modular robots."

The main advantage of using morphological principles observed in nature to generate collective robot behavior is that these principles allow robots to self-organize themselves in a way that is 'guided', 'predictable' or 'controllable'. Nonetheless, self-organizing systems (i.e., systems without centralized control) also typically have a number of limitations.

For instance, defining local interaction rules for generating a desired group behavior in these systems can be highly challenging. In other words, predicting and controlling the systems' global behavior when given a set of define local rules is difficult.

In their work, Jin and his colleagues tried to overcome this limitation by using simplistic robots that are fairly basic and are not capable of self-localizing themselves. Applying morphological principles to these 'minimalistic' robots could enable more effective group behaviors, such as target surrounding or team formations.

"The main difference between our recent work and previous studies is that we use very simplistic robots (e.g., the kilobots we used in our experiments) that do not have self-localization and orientation capabilities," Jin said.

In biological development, cells are guided to a desirable position by a type of chemical called morphogens, or more specifically morphogen gradients (i.e., the change in the concentration of morphogens in an animal's body). Morphogen gradients can either be predefined, as they are, for instance, in the uterus (i.e. maternal morphogens) or established through what is known as 'morphological development'.

In their study, Jin and his colleagues drew inspiration from a process called biological morphogenesis, through which cells generate morphogens themselves as an organism develops. While in nature these morphogens are then used to guide cells to specific locations, the researchers tried to replicate this principle to guide robots and shape their group behaviors.

"During the self-organization, targets and the robots can generate edge morphogens that can be sensed by the neighboring robots (within the sensing range of the robots)," Jin said. "The robots receive information simulating morphogens from its neighboring robots and also pass such information to neighboring robots, by simulating the reaction and diffusion process of biological morphogens."

In their experiments, the researchers assumed that robots can only sense objects (e.g. targets or other robots) within their sensing range. The robots they used, called kilobots, did not possess any self-organization and orientation capabilities.

The researchers reproduced morphogenetic principles observed in nature by using the gradient (i.e., the difference in concentration) of artificial 'morphogens' to guide the movements of multiple robots, so that they effectively reached a desired destination and produced specific group behavior. In a series of preliminary tests, their hierarchical gene regulatory network (H-GRN) allowed robots to autonomously move towards a destination that was not predefined, surrounding targets or forming a specific shape.

"We found that by learning from biological morphogenesis, simplistic robots without self-localization capability (i.e., the capability of determining their own coordinates in a given environment), such as kilobots, can evenly surround moving or stationary targets in a self-organized way," Jin said. "Most previously developed approaches to produce collaborative robot behaviors, on the other hand, are designed for robots that know their own position."

The new hierarchical gene regulatory network (H-GRN) developed by this team of researchers has several advantages over other existing methods for producing collaborative behaviors in robots. Its primary advantage is that it can be used to shape the behavior of hundreds or even thousands of robots, allowing them to complete target surrounding or tracking tasks without centralized control and without any prior information about the targets.

In the future, the algorithm developed by Jin and his colleagues could enhance robot cooperation on tasks that require more complex behaviors and that cannot be accomplished by a single type of robots, especially in situations that involve substantial human-robot interaction. The researchers now plan to investigate the potential of their techniques for tackling real-world problems, for instance in missions aimed at detecting pollution of the oceans, tracking leaks of dangerous gases, or identifying fires in large forests. Their algorithms could also potentially be used to generate group formations for flying of micro satellites or UAV swarms.

"In our future studies, we are going to develop heterogeneous self-organizing systems in which there are different classes of robots, e.g., some of them may have more advanced capabilities, some more basic ones, and others may also be able to communicate with human users," Jin said. "This should allow us to generate more powerful, highly robust, yet highly controllable collective behaviors."

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