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Modular Robot with Adaptive Connection Topology

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The focus of this study is to build hardware modules that can be arbitrarily connected to form robots with various morphologies. The modules have an ability to adapt the arbitrarily-set initial topology in producing a new topology which allows the modules to synchronize their behavior as an integrated robot. We consider that this self-configurability of hardware module can potentially simplify the costly designing process of complicated robots and at the same time improve the resiliency of modular robots in the face of environmental changes and partial internal failure.

1. Introduction

In recent years we have been observing significant increase in the demand for robots outside their traditional manufacturing fields. It can be predicted that in the very near future, robots with various morphologies and tasks will play active role in our daily life. Soon, the conventional manufacturing process which requires thorough designing and assembling will face difficulty to fulfill the increasing demands. For addressing this problem, a young field of modular robotics[1)–4)] has been extensively studied. The main idea of this field is to propose some novel means for self-assembling complex robots from many simple modules.

The main objective in this study is to propose and build hardware modules that can be arbitrarily connected to form robots with various morphologies, without having to run the costly designing process. As opposed to the traditional robotics modules where the connections between them must be carefully engineered, our modules have an adaptive mechanism to automatically discover a connection topology that allows them to generate a target overall behavior as one robot. Similar to the previous studies[6)], here, each module acts as an oscillator, and the cumulative behavior of them produces a Central Pattern Generation (CPG) that governs the overall behavior of the robot. Traditionally in CPG, the connections between the oscillators have to be designed and fixed. However, a fixed topology prevents the CPG to adapt to the changing morphology, environment or task, thus limiting its flexibility. We believe that the adaptive characteristics of our modules can potentially improve the flexibility in robots' construction techniques and also improve resiliencies in the face of external and internal changes including partial malfunction. In this paper we give a brief report on some hardware experiments that have partially been described in our previous paper[8)].

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2. Module and Modular Robot

In this study, each module constitutes a microprocessor, power supply, actuator and connection ports. Independently, each module can only generate simple movements. The idea of this study is to combined several modules in an arbitrary manner and through an adaptive mechanism, let them discover a connection topology which allows them to generate a more complex coordinated behavior as a single robot. Here, the task of human is to give the evaluation function that reflects the target behavior and to arbitrarily set the initial connections. The example of a simple modular robots constructed by combining six modules is shown in Fig. 1. The movement of each module is associated with the phase of an oscillator implemented in the module's microprocessor. The combination of several modules generates a kind of Central Pattern Generator (CPG) which dynamics are as follows. The connection topology of these modules is adaptively altered using Simulated Annealing[7)] to satisfy an evaluation function associated with the target behavior of the robot.

$$\begin{aligned}\frac{d\theta_i(t)}{dt} &= \omega_i - \sum_j \epsilon_{ij} sin(\theta_i(t) - \psi_{ij} + \eta(t))\delta(T_j - t)\\ &\epsilon_{ij} \in \{1,0\}, \epsilon_{ii} = 0\\ &\epsilon_{ij} \neq \epsilon_{ji}\end{aligned} \tag{1}$$

$$\delta(t) = \begin{cases} 1 & t = 0 \\ 0 & t \neq 0 \end{cases} \tag{2}$$

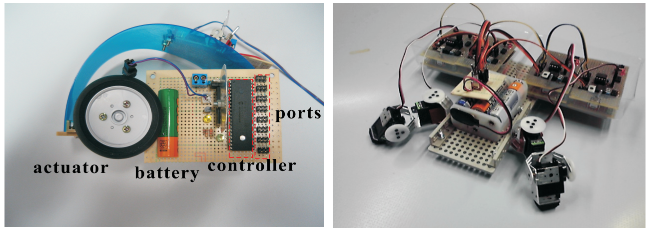
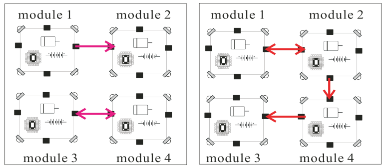


Fig. 1 Hardware Module and Modular Robot



initial topology　　final topology

Fig. 2 Topology Adaptation

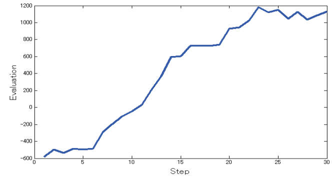


Fig. 3 Evaluation

Here, $\theta_i(t)$ is the phase of the module i at time t, ω is the intrinsic angular velocity which is common for all modules, ϵ_{ij} denotes the asymmetric connection between module i and module j, which value is 1 when the connection exists and 0 when it is severed. ψ_{ij} denotes the ideal phase difference between modules i and j, while $\eta(t)$ shows the introduced random perturbation at time t, and T_j denotes the time when the phase of module j is 2π. Equation 1 shows that module j only sends signal to other connected modules when its phase is 2π. When a module receives a signal from another module it modifies its angular velocity so that the phase difference between the two modules moves closer to the given ideal phase difference ψ.

3. Experiments

In this paper we report on an experiment in our previous paper[8]. The four servo motor modules are assembled to form a robot shown in Fig.1. The connection topology of the four modules was initially arbitrarily set. Here, the task is to generate a connection topology that allows the robot to crawl. The overall behavior of these modules as a single robot is evaluated by attaching acceleration sensors. The values of these sensors are then utilized as an evaluation function for the SA mechanism to gradually develop a topology which allows the robot to generate a targeted coordinated movement.

Figure 2 shows the development of the connection topology, where it is obvious that the initial topology cannot the target behavior while the final topology can. Figure 3 shows the gradual development of the evaluation received by the robot as the implication of its coordinated behavior, where a large value indicates the large movement of the robot. It is obvious that the collection of the modules gradually develop a connection topology that allows them to generate the target behavior.

4. Conclusions

In this study, we built several hardware modules with an adaptive topology mechanism. The modules can potentially not only simplify the production process of robots but also increase the resiliency and flexibility of the generated robots, which are crucial for their operability in unpredictable environments.

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