SELF-RECONFIGURABLE MODULAR ROBOTIC SYSTEM

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Abstract

We present a novel concept of self-reconfigurable robotic system made of homogeneous autonomous robotic modules. Each robotic module has only two DOP, however a group of this module is able to change its connective configuration by changing their local connections. A cluster of the modules, thus, can metamorphose into arbitrary configuration according to the surrounding environment or desired specification. Not only this ability of structural metamorphosis, the combined modules have functionality of robotic system which is capable of generating complicated motion.

Keywords: Self-reconfigurable modular robot, Three dimensional self-assembly, Motion generation

1. INTRODUCTION

Artificial systems have a tendency to become more and more complicated, and cost of design, production and maintenance turned out to be a huge burden on our society. One of new methodologies to cope with this issue is the "Emergent System."

Although there are many interpretations of the concept of emergence, it is generally agreed that the main topic in the emergent system is how to realize a methodology to acquire new functionality by the artifacts themselves. In other words, how to adjust the system to the change of the environment or the modification of the specification, while the adjustment is done by the system itself without external help.

There are several approaches to embed such functionality into the system. Many studies put emphasis on theoretical/algorithmic side of the problem. In such studies, a new theory/algorithm is usually applied to conventional systems such as a robotic manipulator, a mobile robots, or even the whole production system.

We rather focus on the other side of the problem. Our approach is to change the hardware structure of the system to realize the emergent functionality. If the system is capable of changing its hardware structure according to its surrounding environment, its adjustability is much larger than that only by algorithmic effort. Over the past decade, several attempts have been made in the category of "self-reconfigurable mechanical system" made of many units capable of rearranging local connective situation. Such system can metamorphose into any desired shape and change its functionality without external help. We believe this self-reconfigurability is essential in hardware realization of the emergent system.

The CEBOT (Fukuada and Kawachi 1990) is one of the first self-reconfigurable systems, where the modules in the system were heterogeneous such as mobile module with wheels, bending module for a part of an arm, and a hand unit as an end effector. Each unit has connection mechanism and they are automatically combined to form a manipulator. The fracta system (Murata et al. 1994) and the self-reconfigurable robot (Chirkjian et al. 1996) are two-dimensional modular type system. The systems are composed of homogeneous units which do not have any specific functionality. But the group of units is supposed to have some useful function such as handling object or moving on the terrain. Homogeneity of the system is especially advantageous in self-repair operation, because any unit can be replaced by any other unit. Several algorithms of self-assembly and self-repair have been developed for these systems (Chirkjian et al. 1996, Yoshida et al. 1997, Tomita et al. 1999).

Recently, the three dimensional self-reconfigurable system has been frequently discussed. There are two types of 3-D self-reconfigurable system. The first category is a lattice type system (Murata et al. 1998, Yoshida et al. 1998, Unsal et al. 1999, Kotay et al. 1998, Rus and Vona 1998), in which modules form a lattice structure with some spatial symmetry. For instance, our 3-D system can construct a jungle-gym like structure, and the robotic molecules can make a honey comb (Kotay et al. 1998). This type of system is suitable to build various shape as a whole, however, it is difficult to generate group motion. The second category is linear type system (Yim 1994, Hamlin and Sanderson 1998, Will et al. 1999). It is basically a serial link robot made of many joint modules. By in-
cluding fork modules, it is possible to build robotic tentacles by the modules. Although the second type is straightforward way to build some robotic system, self-reconfiguration among the modules becomes very difficult in this type.

In this paper, we propose a self-reconfigurable modular robotic system which has advantages of both types; self-reconfiguration capability and robotic motion. As the lattice-type system, the system can metamorphose into various shapes without external help, then it functions as robotic system such as legged walking machine. In the following sections, we will explain basic design of module hardware, its self-reconfiguration method and shape change process by computer simulation.

2. DESIGN OF ROBOTIC MODULE

We propose a robotic module which is an autonomous element of the self-reconfigurable system. Each module has an onboard micro processor and digital communication device, thus the whole system works as a distributed intelligent system. We use only one kind of module in order to maintain homogeneity of the system.

The robotic module is made of two cubic parts connected by a link (Fig. 1). Owing to its half-circular shape, each of the cubic part can rotate by 180 degrees about the axis joining the link and the cube. These rotational motions are actuated by two servo motors. This motion enables a group of modules to reconfigure themselves. Output axes of the servos are directly connected to the cubic parts, thus no additional mechanism is necessary. The size of the cube is 66 mm in the first prototype which is under construction.

Each cube has three connection mechanisms on its sides to connect with other modules. We adopt the basic idea of "Internally-Balanced Magnetic Unit (Hirose et al. 1986)." This mechanism keeps the magnetic potential energy in non-linear springs to minimize energy consumption (Fig. 2). Attraction between permanent magnets are slightly larger than repulsion of non-linear springs. But this relation is reversed when the shape memory alloy (SMA) coil is activated, (the SMA coil extends when it is heated by electric current) and it is easily detached. Note that the strength of connection force by the magnets is not affected by this mechanism.

Fig. 2 Inter-unit connection mechanism.

In the prototype model (Fig. 3), we use four pairs of rare-metal permanent magnets ($\phi = 10$mm, $l = 3$mm), and measured connecting force was 3.6 lbf. When SMA is activated it was reduced to 0.3 lbf.

Fig. 3 Prototype of connection mechanism.
The robotic module has an onboard microprocessor (PARALLAX: Basic Stamp II, 20 MHz) and other circuits which control the servo motors and the connection mechanisms (Fig. 4). For the sake of convenience, we assume a host PC which downloads programs to each module, and monitors internal state. Serial communication channel and power (12 V) are supplied through the bus line. Contact electrodes are embedded on each surface of connection mechanism to keep the module attached to the bus line.

3. SELF-RECONFIGURATION METHODS

Figs. 5–7 illustrate basic reconfiguration process of the robotic module. One of the basic motion of the module is translation on a plane tiled by the same modules. There are two different modes of translation; translation by a forward roll of the module which is restricted on a line (Fig. 5), and translation by horizontal motion which enables the module to traverse the plane to any direction (Fig. 6). There also exists a procedure to transform one mode to the other. In Fig. 7 the left
module in horizontal motion mode is lifted and settled in forward roll mode. By combining these basic modes of motion, we can construct arbitrary three-dimensional structure without any external help.

4. ROBOTIC MOTION GENERATION

The modules can make not only an arbitrary three-dimensional structure but also a robotic system which possesses a functionality of motion. Figs. 8 and 9 show some of such configurations as a robotic system.

By using the self-reconfiguration method in the previous section, the system can change its shape from one configuration to another. In order to do this, we must find an appropriate sequence of basic transformations. At the present stage of development, this sequence must be hand-coded by human programmer. We have built a simulator of the modular robotic system to design the sequence and verify its results. Fig. 10 illustrates an obtained sequence of transformation, where the modules in planar configuration transform themselves into a legged walker. In this simulator we can also input a motion plan to the assembled modules. After com-
pleting the self-reconfiguration, the legged walker can generate a walking gait.

The next stage is to achieve a semi- or fully-automated self-reconfiguration of the system. For this purpose, we have been developing some utility software such as collision detector and GUI for the simulator. Their detail will be reported in our future papers.

5. CONCLUSION AND FUTURE WORK

We proposed a novel modular robotic system which is capable of self-reconfiguration. The concept of the modular system and its hardware design are described. We have shown that the system can perform both self-reconfiguration of desired structure and robotic motion generation by combining basic motions of modules.

In order to realize "true" emergent system, the environmental change and/or given specification must be reflected in the system. The next research target is to build a self-reconfiguration algorithm for the new modular robotic system by extending formerly developed methodologies (Tomita et al. 1999, Yoshida et al. 1998) for 2-D and 3-D lattice-type system.
References


