Review of Modular Self-Reconfigurable Robotic Systems

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Abstract. Modular self-reconfigurable robotic system has been presented for more than 20 years. We will review the development of the system in this article. There are many categories of the system. Each category is introduced in detail in this article, and typical examples of each categories will be presented. We also present the key technologies of the system.

Introduction

Modular self-reconfigurable robotic systems are composed of many little blocks with uniform docking interfaces which allow transfer of mechanical forces and moment, electrical power, and communication throughout the whole system[1]. By the means of changing the number and the locations of blocks, the robot can change its volume and morphology. This is the most important advantage modular self-reconfigurable robots own. This advantage makes the modular self-reconfigurable robots can execute different types of missions. Comparing with traditional robots, the modular self-reconfigurable robots are fit for missions which are in the undiscovered environment, such as space discovering, rescuing in mine disaster etc.

The modular self-reconfigurable robots have three advantages over the traditional robots. The first advantage is versatility. The ability to reconfigure allows a robot to form new morphologies which are better suited for current missions. The second advantage is robustness. Modular self-reconfigurable robots can recover from serious damages which caused by internal modules failed, because the system can easily replace the broken modules. The third advantage is low cost. The modules of a modular self-reconfigurable robot are so similar that we can make mass production, and it saves lots of money.

Categories of the Systems

There are two ways to classify the modular self-reconfigurable robot systems. We can classify these systems by geometric structure of the robots, and we can also classify these systems by the way in which the blocks of the system move to its places. In this paper, we choose the traditional route of classifying these systems by the geometric of the system. We classify the systems in three main ways: chains systems, lattices systems and trusses systems.

Chains systems

There are many chain-type robotic systems, now. These systems include a lot of modules, and the modules have few degrees of freedom. Generally speaking, these systems are very flexible and complicated. The earliest chain-type system was Ploypod which was developed by Yim et al[2, 3]. Ploypod system was composed of two types of modules: segments and nodes. The nodes which are cubic are passive modules with docking interface on each surface. And the segments have two degrees of freedom. The segments are active modules which make the robot flexible. This design makes the system can transform into many configurations, such as rolling loop, hexapods biped, etc.

The Ploypod system was very advanced at that time, and it inspired many future chain-type systems.

Castano et al. developed another chain-type modular self-reconfigurable robotic system called CONRO[4, 5]. The modules of this system have gendered connectors which can connect itself with neighboring modules by the same plane. The module has two degrees of freedom. The CONRO system can transform into snake and multi-jointed walker. Shen and Will did an autonomously docking experiment with CONRO system, and had solved the auto-docking problem which was the key problem in this field[6].

Murata et al. developed M-tran (Figure 1) modular self-reconfigurable robotic system[7, 8]. This system has undergone three generations, and made great progress. The modules of this system have two degrees of freedom. This system has been used to perform a lot of experiments. Kamimura et al. used a set of interconnected out-of-phase oscillators (central pattern generators) to get walking gaits with M-tran system[9]. Murata et al. also developed a simulator based on M-tran system to perform self-configuration[10]. This system also allows modules to separate from the whole system to do independent tasks and then rejoin the system[8].

Fig.1. Three generations of M-tran system

Shen et al. developed the Superbot modular self-reconfigurable robotic system[11]. The module of this system is similar to the module of M-tran. Shen added an additional rotational freedom between the other two freedoms. Superbot was expected to discover the space, so it was designed to have great robustness.

Yim et al. developed Ploybot modular self-reconfigurable robotic system[12, 13]. This system has undergone three generations as M-tran. The module of this system has only one freedom. Each module has two docking interfaces to connect with neighboring modules. This system can transform into many configurations, such as loops, legs, tendrils, etc. There are passive cubes in this system which have six docking interfaces but don’t have any freedoms. The passive cube allows the system can transform into more configurations. Ploybot can move at any configurations. For example, it can move fast on the smooth terrain by forming a loop, and it can transform itself into multi-legged walker to move on cragged terrain.

CKbot (Figure 2) modular self-reconfigurable robotic system was improved from Ploybot. Yim et al. added an interesting function to CKbot[14]. CKbot can reassemble itself after serious destruction. Yim et al. also did a research about the rolling of the robotic system in loop configuration, and found the most efficient way to roll[15].

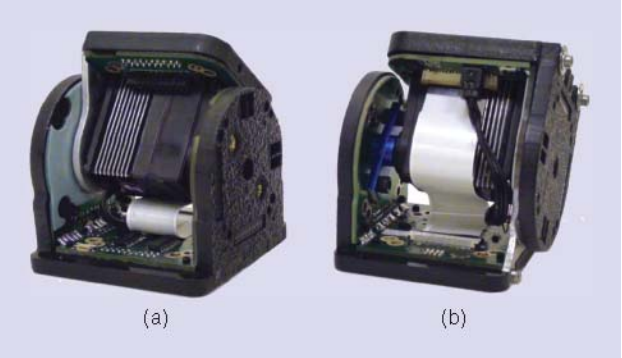

Fig.2. Module of CKbot system

Lattice systems

Chirikjian developed one of the first lattice-type modular self-reconfigurable robotic systems[16, 17]. The modules of this system are deformable hexagons capable of combining with their neighbors. Each joint of the module is driven by a motor and can change the joint angle by at least 120°. The modules of this system can move around their neighbors so that the system can change its configuration. Walter et al. analyzed this hexagon module deeply, and designed distributed motion planners which are capable of reconfiguring the system from one state to another[18].

Murata et al. also contribute to the lattice-type modular self-reconfigurable robotic system[19, 20]. The module they designed is hexagonal and can roll around its neighbors in 2-D. Kurokawa et al. improved this system from 2-D to 3-D[21]. Each surface of this system's module has a rotational arm. These arms can connect with other neighbors and rotate. By this means, this system can change its topological structure.

Rus et al. developed a 3-D modular self-reconfigurable robotic system which can change its topological structure by a series of latching, rotations and unlatching of the molecule system[22, 23]. Each molecule module is composed of two same atoms that have two degrees of freedom. They used mechanical design to connect the molecule modules instead of magnetic force which they used before. Kotay et al. have proved that this system can transform into many configurations, although the molecule modules' movement is limited.

Lund developed ATRON modular self-reconfigurable robotic system which is evolved from the M-tran robotic system[24, 25]. ATRON was expected to own the M-tran's abilities. This system can form different configurations through the connection relationship among the modules. The module of this system has two orthogonal degrees of freedom which is found in CONRO. ATRON system can't form tight structures, so Lund developed the system by making the modules spherical in shape. The module of this system has a single degree of freedom, and has eight docking interfaces. This design makes the system more flexible. Christensen et al. took a set of modules as a virtual module to simply the process of self-reconfiguring[26, 27].

Rus et al. developed Miche modular self-reconfigurable robotic system (Figure 3)[28]. This system can change its topological structure by self-disassembly. Self-disassembly is to remove needless modules from the initial configure to form goal configure. Each module of this system is a 45-mm cube which has three active docking interfaces and three passive docking interfaces. Then Rus et al. improved the Miche and developed the Smart Pebbles[29]. The Smart Pebbles are much smaller than the Miche and use gender-less connectors. The Pebbles are 12-mm cubes which can connect and communicate with its neighbors. This system can change its shapes only in 2-D by the means of self-disassembly.

Fig.3. Miche robotic system

Trusses systems

Most of trusses systems use scalable frame to change its topological structure. One of the first truss-type robotic systems that use telescoping links was Tetrobot robotic system. All links of the system can change length so that the system can easily change its shape[30].

Lyder et al. developed Odin modular self-reconfigurable robotic system (Figure 4) which is composed of three types of modules: active strut module that can change length, passive strut module with fixed length and joint module that has 12 connection points[31, 32]. The joint modules were designed to make the whole system deform a compact cubic structure. The connectors on the strut module can rotate at any direction and make it easy to transform.

Fig.4. Odin robotic system

Biology inspired Nagpal et al. They developed Morpho modular self-reconfigurable robotic system[33]. This system is similar to Odin robotic system. It is also consisted of active strut module, passive strut module and joint module as Odin system. Morpho et al. used the concept of cytomembrane to acquire 2-D and 3-D curves. Nagpal et al. added some interesting applications through the cytomembrane. The cytomembrane can carry an object from a place to another. The cytomembrane can also make the system form a bridge. The "bridge" can adapt rough terrain and make its surface level.

Key Technologies of the Systems

Note that we have listed three categories of modular self-reconfigurable robotic systems and given some typical examples, we can summarize the key technologies of the system as follow.

Automatic docking

The modular self-reconfigurable robotic system is composed of lots of modules, so the process of automatic docking between modules is important. The docking process includes alignment, latching and unlatching. The process includes not only mechanical connection but also the communication and power distribution between modules.

Automatic configuration recognition

Automatic configuration recognition is the process by which the modular self-reconfigurable robotic systems can know their configuration without having it explicitly programmed. With this technology the system can move in any configuration. And the system can realize self-repairing, because it can restart in any initial configuration.

Distributed control system

The modular self-reconfigurable robotic system are composed of many modules. Yim points out that the modular robot's time will come when the robot is consisted of 1000 modules[1]. When the number of modules reaches 1000, it will be difficult to control the robot by the means of centralized control. So distributed control system is important to the modular robotic system.

Conclusion

Modular self-reconfigurable robotic system will make great technological advances to the field of robotics. The advantages mentioned above may lead a great change in automation. Currently, many groups around the world do the related research and have made some progress. By presenting key technologies, we hope that we can show the future direction of the modular self-reconfigurable robotic system.

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