

The Ionic bonding Modules for Self-Reconfigurable Robot

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Abstract—The attraction force is the most common strength to form different shapes especially between atoms, ions and molecules. By self-reconfiguration process, different formation is rearranged. In artificial constructions, this concept will become essential to design and produce the attraction force for reaching the ability of self-reconfiguration. Based on these considerations, a self-reconfigurable robot system is realized with a collection of mechatronic modular robots, each modular robot has the ability to connect and disconnect with others. The proposed paper is focused on two fold: the first concern is about the exploitation of attraction force from the interplay between the control and mechanical systems; the second is related to the implementation of the different shapes among the modules. Preliminary experimental tests of self-reconfigurable robot are taken places to demonstrate the self-reconfigurable operation.

I. INTRODUCTION

IN the nature, the attraction force is the most common strength. This force can be observed widely between atoms, ions or molecules. For example, the chemical bond refers to making up the strength of interacting between the particles of molecules or the material, among them the particles may be atoms, ions or molecules [1]. The chemical bond includes the ionic bond, covalent bond, etc... Ionic bonding is a type of electrostatic interaction between atoms which have a large electronegativity difference. It is a bond formed by the attraction between two oppositely charged ions and self-reconfiguration processes. Even in artificial constructions, this concept will become essential as the system to be designed how to produce attraction force for reaching the ability of self-reconfiguration.

As the discussion above, several self-reconfigurable modular systems are proposed as a group of individual modules [2-19]. These individual modules usually comprise computational and communication capability, and actuators. The actuators are able to change the shape of the modular system for different functions and environments. By changing the status of connectivity between modules, the shape of the reconfigurable modular system can be reformed.

The hardware development of the modular robots for changing shape has been significantly challenged. A team of modular robots should work cooperatively to be able to

operate autonomously. Furthermore, related control software algorithm should be designed for coordinating the team of modules to, for example, change the shape in a distributed fashion. Each of the existing systems has a unique mechanical module design, all with unique implications on robot motion capabilities, structural stability, speed of reconfiguration etc. An important and difficult aspect of the mechanical design of each module of the systems is the design of the connector. Depending on the connecting mechanism of modules, there are two types of them between modules used to lead to the different outcomes of connectivity, contact type and non-contact type, respectively. The modules using mechanical elements to change and remain the status of connectivity are cataloged into contact type e.g. using link, pin/hole, groove and hook. On the other hand, using electrical force and magnetic force to realize the demanding connection situation is called non-contact type.

The proposed modules use magnetic force to change the status of connectivity between modules in order to rearrange the formation of the modular system. For realizing electrostatic interaction, the most effective method is to use the electromagnet and permanent magnet. Electromagnet can change the polarity and the strength of force simultaneously but permanent magnet doesn't. The design of reconfigurable modular system based on ionic bonding modules are proposed in this paper.

In this paper, one single novel actuation module self-reconfigurable robot is proposed. Each module has eight sides and is fully self-contained; it has its own micro-controller, power supply, and actuators. The actuation is driven by magnetic force which can provide both attraction and repulsion force. Also, only one single type of electromagnet is used to generate both the movement and connecting action. Hence, the module just only use one kind of actuators for the functionality of movement or connection at the same time. The mechanical hardware and model design of the module are is described in detail. Related experimental tests of the proposed robotic modules are also presented.

The contents of this paper are as follows. The philosophy of design of modular robot is dissected in Section II. The mechanical design of the module is presented in Section III. In Section IV, the electrical design of the module is introduced. Experimental tests are discussed in Section V, and conclusion is provided in Section VI.

II. PHILOSOPHY OF DESIGN

A typical example in the ionic bond is sodium chloride. From Fig. 1, when sodium (Na) and chlorine (Cl) are

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combined, the sodium atoms each lose an electron, forming a cation (Na^+), and the chlorine atoms each gain an electron to form an anion (Cl^-). These ions are then attracted to each other in a 1:1 ratio to form sodium chloride (NaCl) in order to accord with octet rule. The octet rule is a simple chemical rule of thumb that states that atoms tend to combine in such a way that they each have eight electrons in their valence shells. In simple terms, molecules or ions tend to be most stable when the outermost electron shells of their constituent atoms contain eight electrons [1].

The basic shape of the modules is that of some segments connected in a disc, as shown in Fig. 2. These segments provide the module with attraction and motion capabilities and simulate gaining or losing the electrons. The face of each segment allows it to connect to other module. A set of these modules can be connected together to make complex robots. The shapes of these complex robots can simulate the connection relation between molecules or ions like H_2O and NH_3 shown in Fig. 3. A new type robot is created by merge or releases some of its modules.



Fig. 1. Lewis diagrams of the ionic bonding of NaCl .

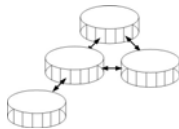


Fig. 2. Basic shape of a module



Fig. 3. A H_2O and NH_3 reconfigurable robots

III. MECHANICAL DESIGN OF THE MODULE

Based on the philosophy of design, a novel module had been developed suitable for 2-D shape reconfiguration and motion generation. Our implementation of the module has two parts: a electrical part and a mechanical part. Fig. 5 shows the CAD design of the prototype model of the module and the physical prototype is also illustrated in Fig. 4. The module is composed of a round surface with e-type electromagnets on the surface which allow the modular system to change shape as well as its locomotion via the connection and disconnection of the electromagnets. In the proposed module, each module consists of eight electromagnets on the disc plate and four steel ball rollers under the plate. Those steel ball rollers can be slipped freely in any direction. The electromagnets being embedded in the round surface work as the main actuators of the module. Each module has its own microprocessor system to control the actuators which has been placed on the top of the module. Currently, there is no facility of communication between modules; all operations must be performed in a distributed realization. In the following subsections, the features of the proposed module

will be well described. The round shape of the module has a peculiar advantage for the self-reconfigurable system that the round shape of the module allows it to vary form more smoothly.

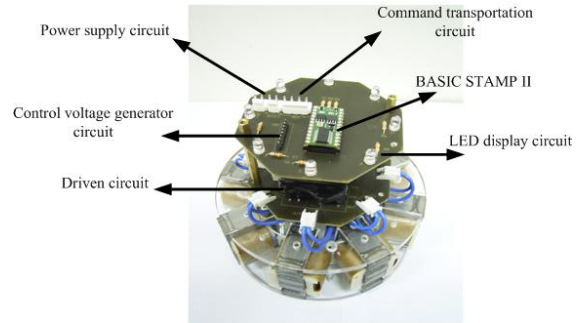


Fig. 4. Parts of the physical prototype module

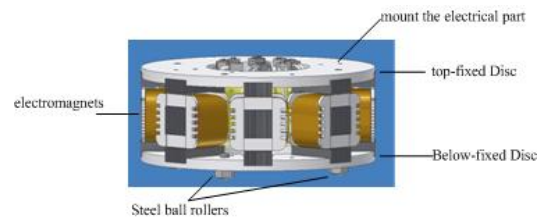


Fig. 5. CAD model of robotic module

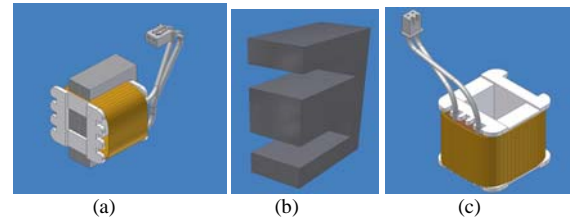


Fig. 6. (a) CAD model of electromagnet (b) iron core (c) winding

A. Actuation System

The actuation system is the most important part of the module. It is made up by electromagnets. Electromagnet use most frequently on industry at present is e-type. The CAD design of e-type electromagnet is shown in Fig.6 (a). Fig. 6 (b) shows the CAD design of core. Cores consisted of stacks of laminations; patterns cut or stamped out of thin sheets of electrical steels. Most applications required a lamination pattern (or patterns) that would form a closed magnetic loop when assembled together. Patterns were sought that were easy to assemble, could be interleaving to minimize gap effects, and would minimize waste. The winding coil is shown in Fig. 6 (c). It is one of the basic electromagnetic devices; it provides the actuation force of the module.

Since "E" cores have two open coil sides, they provide substantial room to bring high current lead wires out from the coil. This also permits good heat dissipation. Because the core stack is a stack of laminations the typical stack has core legs of rectangular cross-section. Typically the inductor or transformer coil is placed over the center core leg as Fig. 6 (a). To minimize winding resistance (hence also minimize winding losses) it is desirable to have a round center leg. A round center leg also eliminates the sharp bend encountered

when winding wire around a rectangular leg; consequently a round center leg permits use of larger wire.

Since the electromagnet is directly mounted on the round surface of the module, no additional mechanism is required to realize the connectivity status of the module. With proper design, the e-type electromagnet can provide enough attractive or repulsive force between modules to change the shape of the modular system.

When one module connect or disconnect to other modules, the electrical steel stamped out of two adjacent “E” laminations (placed leg end to leg end) to form the winding window area became the two “I” laminations to be placed across the leg ends of the “E” laminations. In the typical “E” lamination, the center leg (one of three legs) is twice the width of either outer leg. In theory, magnetic flux flowing out of the center leg divides equally and flows into the outer two “E” core legs [20]. Since the outer legs handle half the flux they only need to have half the cross-section that the center leg has. An “E” core structure occupies two outer sides of the winding coil. In contrast, a “U” core or “C” core structure (which has two core legs) only occupies one side of a coil placed over one of its legs. The “E” core structure provides better self-shielding than the “U” core structure (but neither provides good shielding).

IV. ELECTRICAL DESIGN

The electrical part of a module contains the control board and driven board (Fig. 4). The control board includes an onboard microprocessor (BASIC STAMP II, Parallax, Inc.), a power supply circuit, command transportation circuit, control voltage generator circuit and LED display circuits. The microprocessor has a dipswitch input to set an ID number of the module.

The magnetic forces of the electromagnets are controlled by adjusting voltage signals generated by the microprocessor and sent to the driven circuits. To build a connection to another module, the microprocessor drives the driven circuit in the driven board by command voltage. When a connection is built up, the connection surface check the connection status (connected or disconnected).

A schematic diagram of the control system architecture is shown in Fig. 9. It consists of the host PC, distributed microprocessor (the same one as in the module) and modules. All communication is 4800-b/s asynchronous serial communication. The host PC and the distributed microprocessor are connected by ordinary bilateral communication, while single-wire communication with token passing is adopted between the distributed microprocessor and modules to reduce the number of electrodes. First, the host PC issues a control command that includes the module’s ID number. The distributed microprocessor then broadcasts the command to all the modules on the serial bus. A module sends back a validation signal if its ID coincides and executes the command. After the execution of the command, it sends a completion signal to the host PC via the distributed

microprocessor. When no validation is returned from the module, the host PC sends the command again for recovery. There is no restriction on the network topology. Module specifications are summarized in Table I.

TABLE I
SPECIFICATION OF THE MODULE

Item	Value
Dimension	ϕ 13.5mm
Weight	1.5kg
Communication	4,800 bps (asynchronous serial communication)
Power supply	DC40V(electromagnet) DC9V(microprocessors)
electromagnets	#8
driven circuit	#8

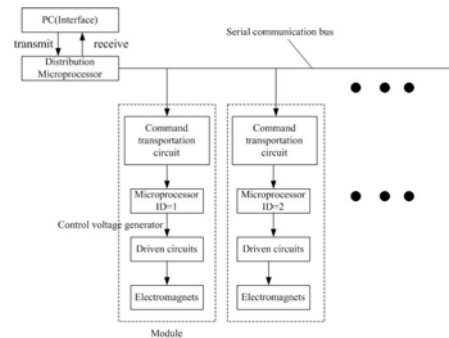


Fig. 11. Schematic of the control system architecture

V. EXPERIMENTS

We build three modules based on the design explained in previous sections to test the actuators and model design of the module. Their bodies have the same structure that the modules configured as a line would have.

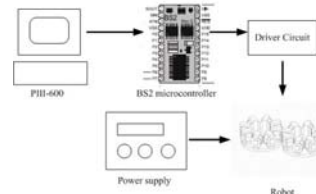


Fig. 12. Experimental setup

The electromagnet pair was used to attract each other for the form procedure. The specification is given in Table II.

Fig. 12 shows the experimental setup of these modules. The modules are free, controlled from a host PC and powered by an external power supply. The eight electromagnets are actuators driven by eight relay circuits. The control software is composed of two programs. The first program provides an interface to a library of functions, serial port and controller drivers, synchronization routines and a motion scheduler. Second is used to specify motions, their on-off or their duration.

Fig. 13 is a experimental result, test to verify its capacity to attract another module and motion. The glass is used for reducing frictional force. Because the weight of these three modular is nearly equal, they cause rotation in the original position while attracting each other.

It also demonstrates of the self-reconfiguration process of the actual module system. According to the command sequence from the host PC, the modules change their relative connections. Fig. 13 demonstrates of the self-reconfiguration process of the actual module system. From the experiment, three modular are formed as a line in Fig. 13 (a). At Fig. 13 (a) to Fig. 13 (b), two modules are connected together on the right but that module on the left attracts and rotates through the magnetic force. It can achieve the goal of motion through the displacement of the centre of gravity in such a design. These modules are connected in this process. At Fig. 13(b) to Fig. 13 (c), two modules are connected together on the left but that module on the right attracts and rotates through the magnetic force. From experiment, they have finished repeated rotator motion. They are proved that only uses the single type component to make the robot reach the movement and connected characteristics.

TABLE II
THE HARDWARE SPECIFICATION

Size	135 mm (the diameter of the robot)
Weight	1.5kg
electromagnets	8
driven circuit	8
Processor	Basic Stamp II
Power supply	DC40V

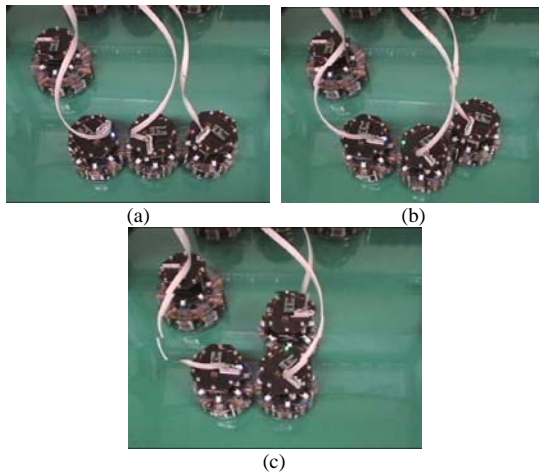


Fig. 13. Schematic of the control system architecture

VI. CONCLUSION

In this paper we have investigated a detailed design of a new type self-reconfigurable robot with the use of electromagnetic force of many mechanical modules. The character of e-type electromagnet is also described. To verify the feasibility of the proposed design, the experiments with the proposed modular robots are given to examine the basic design concept and also the reliable self-reconfiguration operation of the robot. The simple structure and reliable operation of the proposed module enables users to construct self-reconfigurable system in a large scale.

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