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A self-repairing approach for the M-Lattice modular robotic system using digital hormone model

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HIGHLIGHTS

- An improved design of M-Lattice modular robot and its special motion mode are introduced.
- A self-repairing approach planning the movements of holes rather than the spare modules is proposed.
- Digital hormone model taking the endocrine system as a reference is applied to the self-repairing approach.
- Performance of the proposed approach is evaluated by a simulator.

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ABSTRACT

The solar power satellite (SPS) working in outer space offers a way to make full use of solar energy. And the modular robotic system (MRS) consisting of many basic modules is a good idea to construct a large-scale SPS because of its modularity. However, because a MRS of SPS may work for years without human in outer space, the self-repairing ability becomes vitally important. Once a modular robot breaks down, the MRS should replace it with a good one to keep the integrity and usability of system. In this paper, we first introduce an improved design of the M-Lattice MRS that comprises many identical basic modules with honeycomb structure. It also has an interesting motion mode and two prototype robots are built to verify the motion ability. Next we propose a novel self-repairing approach for this MRS and the digital hormones inspired by the concept of hormones in biological systems are introduced with taking each module as an endocrine cell. The digital hormone model (DHM) provides every module with an evaluate value so as to direct the locomotion in the self-repairing process. The concepts of secretion and attenuation as well as two kinds of digital hormones are introduced into the DHM to realize the collision avoidance of holes and faulty modules. In the end, we evaluate the performance of the proposed self-repairing approach with simulations. The simulation results show that the proposed approach is good at both scalability and robustness.

1. Introduction

Energy is a global issue. While more and more people are starting to focus on the renewable solar energy, many researchers think deeply about how to make full use of it. Because of the day–night, summer–winter and weather cycles, only few solar radiations reach the ground. Peter E. Glaser first invented the concept of solar power satellite (SPS) to solve these problems in 1968 [1]. The SPS would be launched into space, placed in geostationary Earth orbit (GEO) to collect sunlight, used to generate an electromagnetic beam and transmit the energy to the Earth [2,3]. Due to the space environment, the SPS should work for years without failure and human intervention. Therefore, the deployable structures [4] used in most satellites today is yet unfeasible since it cannot repair the faulty parts by itself.

To solve this problem, we had designed an M-Lattice modular robotic system (MRS) for the SPS in [5]. In general, the MRS has some attractive properties. For example, the basic modules can be assembled together to complete a task that is beyond the capabilities of any of individuals. So we can store the M-Lattice modules separately in a space rocket, and assemble them together later in space to reduce storage space. Furthermore because of the modularity, the MRS is easy to be repaired by using a spare module to replace the faulty one.

The MRS consists of many intelligent modules that are capable of perception, communication, decision making and actuation. Each modular robot can work independently based on the

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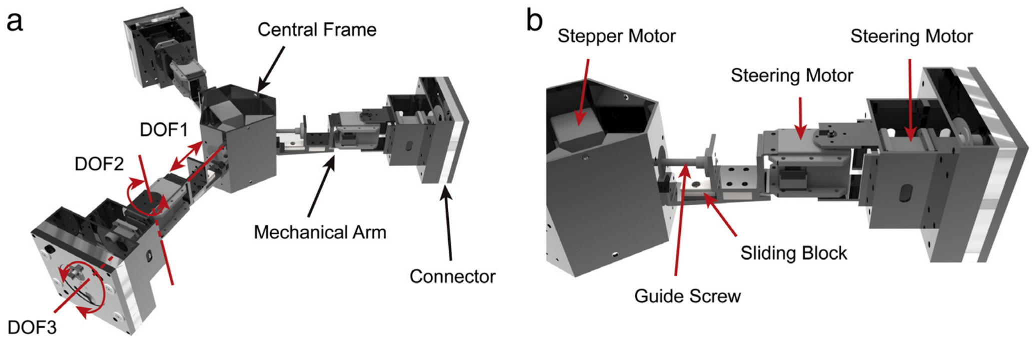

Fig. 1. (a) The M-Lattice modular robot, and (b) the mechanical arm.

information provided by the sensors and communicators. The module's structure is various and the MRS can be classified into three types [6] according to the geometric arrangement of modules: the chain-type [7,8], the lattice-type [9,10] and the mobile-type [11,12]. Moreover, a hybrid-type MRS [13] is proposed to take advantages of several types and can work in the chain-type or lattice-type alternatively. The M-Lattice MRS introduced in this paper is a hexagonal lattice-type MRS. And the hexagonal lattice-type modular self-reconfigurable systems were first proposed in 1994 by two independent groups [14,15]. In these two systems, the modules were homogeneous and could move along the edges of other modules. Furthermore, [16,17] studied the design, path planner and the self-reconfiguration of HexBot. And [18,19] focused on the distributed self-reconfiguration algorithms of hexagonal lattice-type MRS.

Moreover, since the hardware is one of the weak points in robotics [20], the self-repairing ability of MRS becomes an attractive feature. The first self-repairing algorithm for the MRS [21] was proposed in 1999 based on the simulated annealing. The researchers used the self-assembly algorithm to enable the self-repair function by introducing an extended target description. In addition, some researchers have investigated the self-repairing algorithms which use the modified Bresenham's algorithm [22] and the Breadth-First-Search as well as the Depth-First-Search [23].

Furthermore, applying the bio-inspired methods to robotics can be found in many literatures [24–26]. Shen et al. [27–30] first proposed the digital hormone model (DHM) and applied it to the MRS. Their DHM was used to develop an adaptive distributed control protocol applied to the control of the CONRO-like MRS. A hormone-like message was used to collaborate with modules' actions and its propagation was different from the message broadcasting. A single hormone might cause multiple effects in the MRS and the modules receiving the same hormone might behave differently. Moreover, the digital hormones are also applied to the obstacle avoidance in the MRS [31]. The DHM inherits some features [28] from the animal's endocrine regulation mechanism and we summarize them as follows. The first is messenger that the hormone just carries information but without extra energy or function. The second is specificity that the hormone acts on the specific targets and activates the relevant behaviors. The third is diffusivity that the hormone diffuses freely without target in the MRS. The fourth is life cycle that the hormone gradually attenuates with time going on. Most researchers use the digital hormones and pay attention to the features of messenger and specificity whereas the diffusivity and life cycle get less attention. The proposed approach in this paper makes full use of these four features so that the MRS performs well in both scalability and robustness.

The rest of this paper is organized as follows. Section 2 introduces the M-Lattice modular robot. And Section 3 proposes three matrices so as to describe the statuses of modules in the MRS clearly. Section 4 presents the self-repairing approach and Section 5 derives the crucial DHM. In Section 6 a simulator is built to verify the proposed approach with various scenarios. And Section 7 discusses the limitations of this approach and presents the future works. Finally, Section 8 concludes this paper.

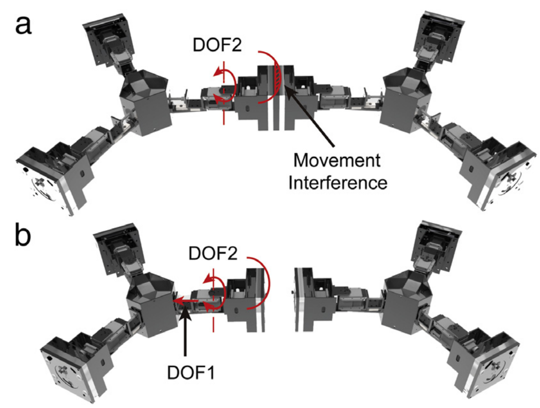

Fig. 2. The movement interference. The movement interference is avoided if the DOF1 works first.

2. The M-Lattice MRS

2.1. Basic module

An M-Lattice modular robot has one central frame and three identical mechanical arms, as shown in Fig. 1. The mechanical structure of M-Lattice modular robot had been introduced in [5]. But in this paper, we replace a rotational DOF with a telescopic DOF in every mechanical arm, in order to avoid the movement interference happening between two neighbors.

The central frame is used to install the microprocessor and also fix the solar panel or other working equipment. Each mechanical arm contains three DOFs: a stepper motor that enables the arm to stretch out and draw back (DOF1, telescopic DOF), a steering motor that enables the arm to rotate (DOF2, rotational DOF), and another steering motor that enables the connector to engage (DOF3, docking DOF). The introduced telescopic DOF consists of the stepper motor, guide screw and sliding block. And this DOF makes module compressible, which is useful for the movements of modules when their neighbors are occupied. Fig. 2 shows the effect of the telescopic DOF through which the movement interference is successfully avoided. We can see that the movement interference occurs when the rotational DOF works whereas it is avoided if the telescopic DOF works first. This property makes the M-Lattice module be capable of moving even if a module is fully connected