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# Self-reconfigurable M-TRAN structures and walker generation

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**Abstract**

The M-TRAN is a modular robot capable of both three-dimensional self-reconfiguration and whole body locomotion. Introducing regularity in allowed structures reduced difficulties of its reconfiguration problems. Several locomotion patterns in various structures were designed systematically using a CPG controller model and GA optimization. Then they were verified by experimentation. Results showed a feasible scenario of operation with multiple M-TRAN modules, which is presented herein, including metamorphosis of a regular structure, generation of walkers from the structure, walker locomotion, and reassembling of walkers to the structure.


*Keywords:* Modular robot; Autonomous distributed system; Self-reconfiguration; Metamorphosis

## 1. Introduction

Several modular robots are under development that can change their configuration independently or perform locomotion in various structures. Their modules' design differs in the number of DOFs, geometric arrangement of DOFs, connector design, information processing and controller, and communication capability with other modules. A comprehensive system of connected modules forms an autonomous distributed system. Software problems include feasible tasks and their representation, reconfiguration algorithms, a centralized or decentralized controller, and coordination between modules.

Most three-dimensional (3D) modular robots are classifiable into two types: a lattice type [1–4] and a linear (or string, or chain) type [5,6]. Self-reconfiguration problems, such as self-assembly, i.e., metamorphosis from one configuration to another, and a cluster flow motion by repetitive local reconfiguration, have been investigated mainly using the former type of system. Whole body locomotion has typically been studied using the latter type of system.

The modular transformer (M-TRAN), which was developed at AIST, was designed to offer features of both lattice and linear types [7]. It can form various self-reconfigurable lattice structures. Once a specific structure is produced, each rotational joint can be driven powerfully to realize robotic motion as a whole. Therefore, both self-reconfiguration and whole body locomotion can be studied using the same M-TRAN hardware.

Regarding self-reconfiguration, several difficulties arise in sequence design and control algorithms. Transformation between arbitrary configurations is a difficult problem, even considering an omni-mobile module and by a centralized algorithm. Distributed algorithms are suitable for cluster flow motions, but they require several methods of maintaining total connection, collision avoidance, and multi-module cooperation. Constraints of respective actual hardware design complicate the problem.

The M-TRAN has numerous kinematic and hardware constraints. For that reason, general self-reconfiguration obstacles are extremely difficult to surmount [7]. We have manually designed reconfiguration sequences for experimentation. Fewer than 10 modules were used in these experiments, including the experiment illustrating transformation from a four-legged walker to a caterpillar structure [8]. For systematic reconfiguration of a larger structure, we introduced types of structural regularity and developed a centralized planner to find a reconfiguration sequence [9].

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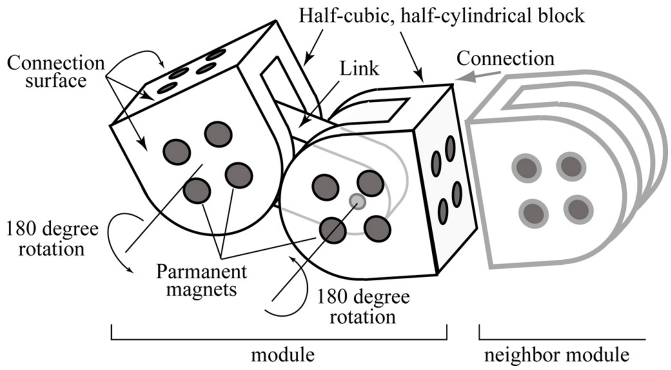


Fig. 1. M-TRAN module design.

Locomotion is another research subject of modular robots. Systematic designs of distributed locomotion control have been proposed for specific topology having symmetry [10,11]. We have developed a systematic design method for locomotion of several M-TRAN structures and verified it by experiments [12].

In most studies above, two problems – self-reconfiguration and whole body locomotion – are dealt with for different size structures, i.e., self-reconfiguration, especially cluster flow motions, for a larger structure and whole body locomotion for a smaller structure. We have shown an example in which a small walker is generated from a structure of many modules [7]. This process of sub-structure generation combines two problems. Therefore, we can draw a big scenario of M-TRAN operation in which a structure with many modules metamorphoses to form a given structure or generates a cluster-flow motion that conforms to the environment: it generates many walkers; the walkers then leave and gather to reassemble another structure.

Section 2 describes principles and the current M-TRAN hardware. An operation scenario is presented in Section 3, followed by past research results of self-reconfiguration and whole body locomotion. Section 4 presents a detailed evaluation of the feasibility of the scenario using several examples of walker generation by self-reconfigurable structures and metamorphosis between walkers. Future work and the conclusion are included in Section 5.

## 2. Modular transformer (M-TRAN)

### 2.1. Module design and motion

The M-TRAN module comprises two blocks, half cubic and half cylindrical, and a link (Fig. 1) [4]. The module has two DOF rotational actuation and six connection surfaces. Each actuated angle ranges ±90 degrees; when all the angles are controlled as 0 or ±90 degrees, all blocks of connected modules are lined up into a regular cubic lattice. By this property, precise positioning between two neighbor modules is not required for a reconfiguration operation. Because the two actuated axes are parallel, reconfiguration of the M-TRAN module structure usually requires cooperation of multiple modules, especially the carrying of one module by another. This renders the reconfiguration process difficult from a design perspective.

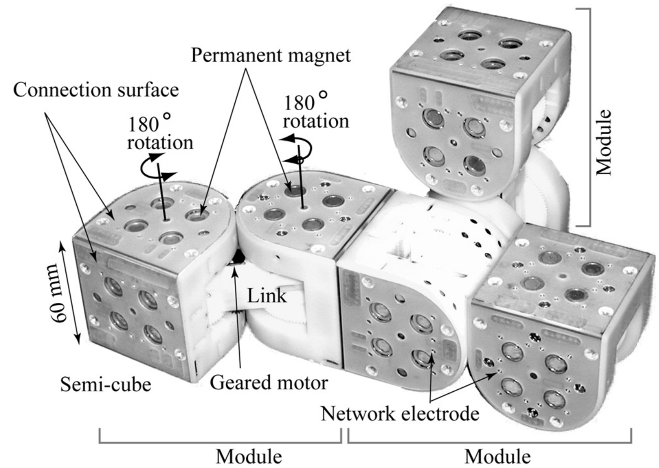


Fig. 2. M-TRAN II.

### 2.2. Hardware

We have developed second-generation hardware called M-TRAN II, as shown in Fig. 2 [8] based on the first prototype [7]. Its motors and connections are sufficiently strong to support and manipulate one or two other modules under gravity. It has sufficient controllability of connection for self-reconfiguration and sufficient actuation power and speed for locomotion. Each module has three micro-controllers that allow it to perform precise angular control, connection, and disconnection. The main controllers of connected modules form a computer network that is suitable for synchronization and cooperation. Installation of a battery in each module allows stand-alone wireless operation. This is an important feature because wires typically obstruct the self-reconfiguration process and interfere with locomotion. One module has an RF receiver, with which an operator sends a command to the modules.

## 3. Operation scenario, self-reconfiguration and locomotion

### 3.1. Operation scenario

We have conducted various simulations and experiments to verify both self-reconfiguration ability and whole body locomotion of the M-TRAN system [8,12]. They include metamorphosis of large structures, generation of a walker from a structure, locomotion in variously shaped walkers, and metamorphosis from walkers to caterpillar-like robots. Combining those results, we can infer a scenario of multi-M-TRAN operation that is useful for several applications such as search-and-rescue operations (Fig. 3).

Among several motions, self-reconfiguration (Fig. 3(a)) and whole body locomotion (Fig. 3(b)) have been well examined. Past research results of those motions by the M-TRAN system are summarized and evaluated hereafter.

### 3.2. Self-reconfiguration

Various studies have addressed self-reconfiguration of modular robotic systems. Tasks vary from self-assembly, i.e.,