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The Influence of Shape for Self-Reconfigured Modular Robotic System Characteristics

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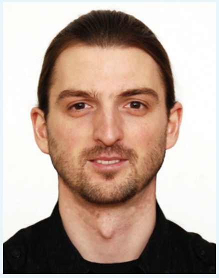

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KEY WORDS

Self-reconfigurable robot, principle design, hybrid module

ABSTRACT

The theory of mechanisms with a variable structure into the application form of the metamorphous self-reconfigurable structure of robots has been recently developed as a possible direction of an innovative approach to robotic technology. In our faculty, we decide to create module for such robotic system. The result is a unique MMR metamorphous robotic system on the basis of an autonomous MG module which is able to act

as a homogenous module, however, at the same time it consists of heterogeneous sub-modules which enable the module to cooperate with other modules and thus create and be transformed into various kinematics structures of robotic system, as may be necessary. Furthermore, the module is able to work as a separate module and to transform its kinematics structure as requested.

INTRODUCTION

Theoretic robotics characterises metamorphic modular robots (MMR) as modular systems capable to flexibly self-reconfigure their own kinematics and functional structure for purposeful creation of a "new" robot with different functional characteristics and technical parameters [1]. A modular robot does not need to achieve the same parameter and functional level as a specialised robot designed for a specific task [2]. The scope of application of such a robot is not as limited as in the case of a specialised robot, therefore. Modular robots are younger than special robots from the viewpoint of their development (use of robot with ability to change its structure dynamically is younger), the scope of their application is wider, and thus, requirements placed on such robots are higher. Technology development up to date can be summarised according to [3, 12] in the following way:

- *Processing of material into required shape.*
- *Processing of material parameters in order to achieve required characterises.*
- *Dynamic change of shape in order to create of a new shape and dynamic change of characteristics in order to achieve new characteristics.*

High potential of the above robots lies in the fact that they consist of modules which are able to change the shape and characteristics of the robot in a dynamic way. MMR characteristics depend on the characteristics and abilities of the module itself so that the module characteristics directly affect the characteristics and abilities of the whole MMR. The module must function as a separate robot [4] but it must be also able to cooperate with other modules without any limitations so that MMR can adapt to new changed conditions in the operation area of the system.

This article intends to explain the principle of a module designed by us called Multi-Group (MG) which was based on the already existing module Molecube [5]. The scope of application of MG is wider that the one of Molecube which is the main reason why these systems should be used. The article is divided into two sections. The first one describes the required characteristics of MMR systems and the second one describes the division of the MG module principal design.

PRINCIPLE OF SELF-RECONFIGURABLE MODULAR ROBOTICS SYSTEM

Self-reconfiguration of kinematic and functional structures of robots means the development of mobile structures by controlling variability within robot structure. It can be developed by increasing/decreasing the number of components which perform the kinematics function or by increasing the proportion of active components in the resultant mobility of the kinematics chain. The principles of kinematics structure change can be derived from the theory of mechanisms with changing (variable) structure, namely:

- *Change in the distance of kinematics chain members.*
- *Change in the number of degrees of freedom of fixed mechanical system:*
  - change of character of kinematic couple bond in the kinematics chain by its blocking or releasing,
  - change in the number of degrees of freedom of the kinematics chain member by joining or division of members,
  - change of character of kinematic couple bond in the kinematics chain by its blocking or releasing,
  - change of kinematics chain character, e.g. from open to closed/mixed.
- *Change in the application of hybrid joints.*
- *Change in the connecting of further members into the kinematics chain.*
- *Change by combination of the above principles.*

The concept and structure of MMR is based on the modular structure, i.e. system of autonomous AM modules and their mutual interconnections and arrangements. Various functional and kinematics configurations of the robot can be achieved by changing the AM mutual interconnections and kinematics configurations of the robot.

MMR are classified as homogenous or heterogeneous depending on the use of one or several types of modules. Heterogeneous modules are designed for a specific task which predetermines their final position within the robot structure. Homogenous modules are identical and their position within the robot structure determines their function [6, 7]. Modules with their advantages [8, 9, 10, 14] and disadvantages [15] affects the properties of MMR.

MMR system can work in two types of structures: lattice and chain structure. Advantages and disadvantages of lattice and chain structure are well described [7, 11]. Besides of these two modules, is possible their combination. These modules we call hybrid modules.

Number of modules and their degrees of freedom has crucial importance for the characteristics of the module system as such, but also for the resultant MMR abilities. For this reason, prior to designing, the number of degrees of freedom must be known for the module which is to be designed for MMR and also the maximum size of possible extension of MMR with reliable function. The following information can serve to specify such characteristics of the module and system more accurately:

- *With the number of used modules, the number of possible configurations grows exponentially and the number of degrees of freedom linearly which makes the modular robots extremely versatile [12].*
- *Additional degree of freedom makes the robot more versatile in its abilities but it also increases mechanical and calculation complexity [2].*
- *Possibilities of changing the shape and size of the robot increase its versatility. However, the increases in flexibility results in limitations of structure and control software design [14].*

Advantages of modular robotics are obvious only then if, with regard to required tasks, several special single-purpose robots would have to be applied or if the environment and tasks cannot be accurately defined prior to the use of the robots [2]. Then it is appropriate to design such module(s) which can cover a maximum amount of tasks. It is easier to adjust the control or algorithms of a complicated module in order to achieve the maximum amount of applicable applications than to invent an application for a module and MMR with minimal abilities and then discover that the module structure has fundamental limitations for multi-use of MMR and needs to be adjusted together with its control.

Based on up-to-now results of MMR system research it is obvious that it is possible to design a module for the system which would be able to support a high degree of transformation, work in 3D space and which would support both chain and lattice structure. The module is designed for work in 3D space and it must meet the following criteria:

- ***Versatility:*** ability to create new robots, robotic groups, each module can work separately.
- ***Resistance:*** ability to resist stress from external load, temperature and inertial forces [16].
- ***Low price:*** low production costs, easy installation, possible mass production.
- ***Large system:*** unlimited number of modules, system of modules which can be divided and connected as necessary into several groups which cooperate with each other.
- ***Self-repair:*** self-troubleshooting, capable to diagnose its status, disconnect or limit damaged component, replace the damaged component or sub-system, sub-module.
- ***Self-maintenance:*** power supply, shares power and is able to find the power supply source.
- ***Self-propagation:*** capability of growth and development of the system, capable to join parts of modules - sub-modules.

PRINCIPLE OF MULTI-GROUP MODULE

The Molecube module has one rotation axis and one division plane, see Fig. 1. This module is divided into two parts by the plane which is vertical to one of its volume diagonals. A module which is divided like this has more options for movement than a square-shaped module with the rotation axis in a different position than its body diagonal. Such module is able to move adjacent fixed modules via rotation part into three possible positions. Apart from the initial position the adjacent module can be moved by rotating the mobile part of the basic module by 120° into further two positions. In principle the situation is the same as in case of the 2D module. If the task requires this and the fixed module must be transformed into the position which is not supported by the module which provides for rotation with regard to its actual connection with the previous module, the rotation of the basic module is necessary or positions of the individual modules in a line must be combined in such manner that the end module reaches the required position and orientation. This increases demands for the recalculation of MMR positions or its correct arrangement in the structure to make their transformation as efficient as possible.

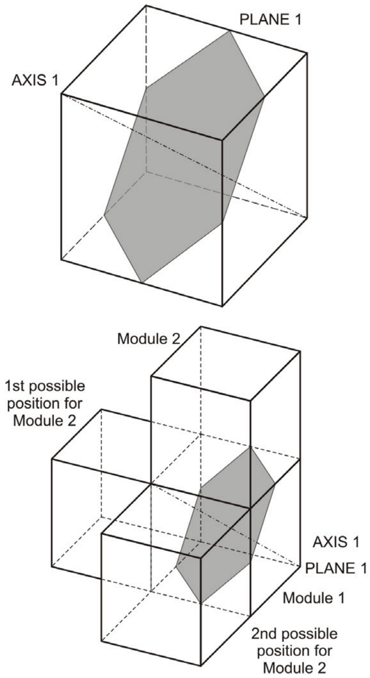

Fig. 1 *Module Molecube and possible positions of connected module*

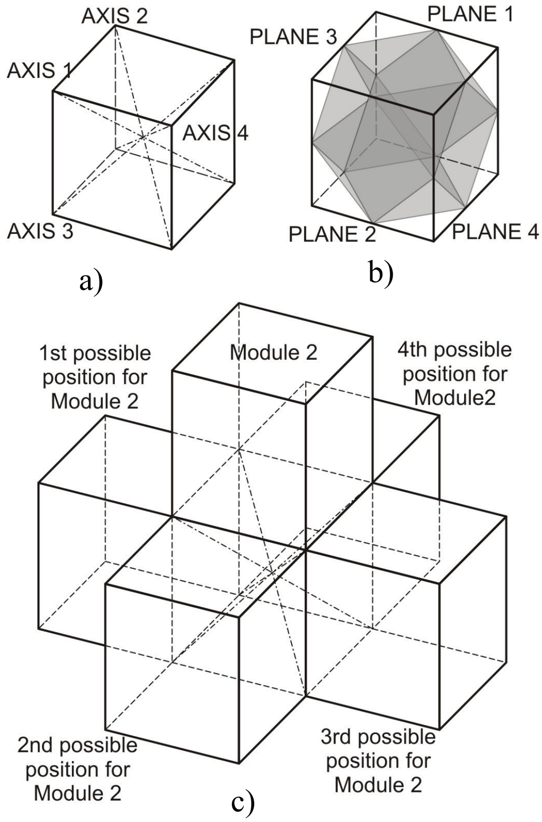

Fig. 2 *Basic axis of rotation (a) and division planes (b) and possible position of Module MG (c)*

With regard to the fact that the condition for the use of these systems is a wide range of tasks it is necessary that the module has a high degree of its own transformability without any unnecessary long periods of time for transformation or movement. For this reason, the designed MG module has additional rotation axes and division planes in order to improve movement possibilities even at the expense of structure and control.
By comparing the existing modules and possible variants which could be created by joining 3D geometric shapes we have come to the conclusion that the best solution for MMR is a cube-shaped module with four applied rotation axes which are its body diagonals. Fig. 2 shows all the basic rotation axes and also all the division planes of the designed MG module. As you can see the division planes will divide this module into several sub-modules which, if they are correctly designed, will enable the module to work in basic axes so that the mobility of the adjacent module is not limited and so that it is able to move from its position into free position within the module which it is connected with.

Sub-modules which have been created by division also include the core sub-module. The sub-module of the core or control (SMR) is one of the basic sub-modules of this module; its task is to provide for rotation around the basic axes. The basic shape of SMR is a cuboctahedron, see Fig. 3(a). It is assumed that, with regard to its position in the module, the sub-module will be used as a basic control component for this module, apart from being used for the provision of movement.
The rotation sub-module (SMO) is the second sub-module which is created by the division of the module via division planes. Volume gravity centre of this sub-module lies directly on the rotation axis. Eight SMO are situated in the module, one in each corner, see Fig. 3(b). During rotation of one of the halves one SMO lies directly in the rotation axis and another three SMO form the tops of the rotating half. The fixed part of the module has the same structure as SMO. Every SMO is connected

with SMR in one point and with connecting sub-module (SMS) in three points. The number of connections varies depending on the actual movement of the module.

SMS is the last one of sub-modules which is created by the division of the module by division planes. The connection side of the module represents its largest surface area. There are six SMS situated in the module, one on each side of this module, see Fig. 3(c). Each SMS is connected with SMO in four points.

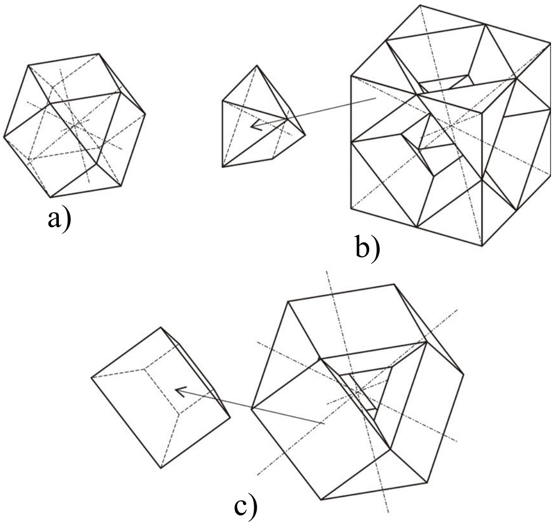

Fig. 3 *Basic shape a) Sub-module of control, b) sub-module of rotation, c) Sub-module of connection*

Our target was to apply the correct design of the parts of the modules/sub-modules, to achieve such situation that the module would be able to transform itself into another module or create a different module with different characteristics out of certain module. To design the module in such manner that it would be able to create a different module with different characteristics without necessity to develop new modules, purely by change of algorithm of control and in this way to improve the characteristics of MMR which consists of MG modules. The module in basic situation in which it doesn't originating tasks has 32 connection pairs. The status changing of these connection parts allows change the shape of the module. Due to limpidity of connection between the individual sub-modules they were divided into two sections. The connections between SMO and SMS which creates covering of module, there is 24 connections, see Fig. 4(a). The connection between SMO and SMR, there is 8 connections, see Fig. 4(b).

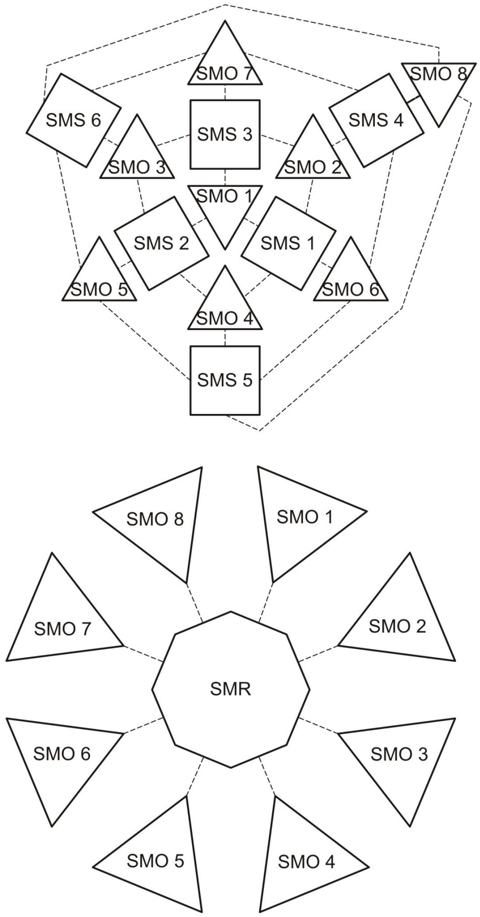

Fig. 4 *Connection between the sub-modules*

The basic shape is adapted to shape in which the module has no limitation in movement, in basic structure neither in re-configuration of module. Fig. 5 shows a virtual model of the designed MG module which is able to transform itself into a different structure of the module as you can see in Fig. 6.

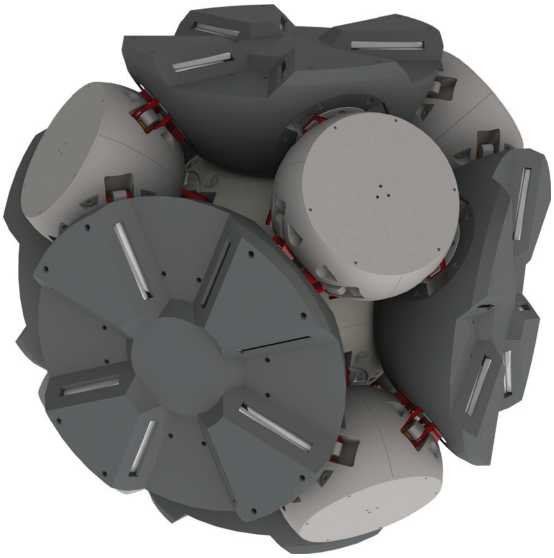

Fig. 5 *Module MG*

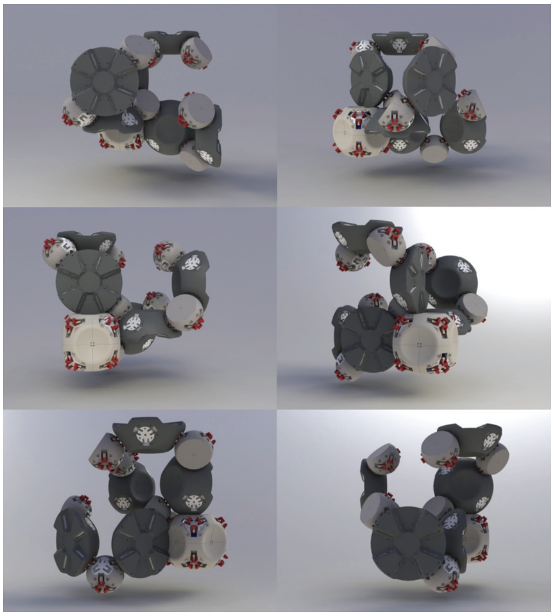

Fig. 6 *Module MG in transformed structure*

CONCLUSION

Metamorphic robotic systems have a huge potential of application in various fields, but only if the given MMR will be able to replace a higher number of special robots applied to resolve the given problem in one place. For this reason these systems must be designed in such manner that they are able to fulfil this requirement. The introduced principal design of the MG module has preconditions to become such system. It is able to work in its basic function in the basic shape of a square. It is able to lock its shape so that it can create fixed parts of the system without any need to slow down the motors. This principle, as it was described, is able to transform its module into a different shape of the module and thus to create a new module without any need to construct any further modules. Such complex module would be able to cover a wide range of application robotic tasks.

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