Modeling Lattice Modular Reconfigurable Systems with Space Groups

Nicolas Brener
Laboratoire de Robotique de Paris
18, route du Panorama - BP 61
92265 Fontenay-aux-Roses Cedex
Email: brener@robot.jussieu.fr

Faiz Ben Amar
Laboratoire de Robotique de Paris
18, route du Panorama - BP 61
92265 Fontenay-aux-Roses Cedex
Email: amar@robot.jussieu.fr

Philippe Bidaud
Laboratoire de Robotique de Paris
18, route du Panorama - BP 61
92265 Fontenay-aux-Roses Cedex
Email: bidaud@robot.jussieu.fr

Several modular systems have been developed, one can distinguish lattice systems [1], [2], [3], [4], [5], [6] and chain type systems [7], [8]. A review on these systems can be found in [9]. Today there is no theoretical background for the kinematical design of modular systems. To design a new module one must choose the relative positions of components like mobilities and connectors. These positions are continuous quantities, therefore there are infinite possibles choices. Moreover one must choose the symmetry of the connectors, the type of mobilities and their workspace.

To help the design, we provide a way to drastically reduce the possible choice by discretizing the positions of the elements, thus the space of parameters is no more continuous but discrete. We discretize the positions and orientation of the connectors, and also the position/orientation of the mobility axes and the state of the actuators. To do this we use an already existing knowledge from the domain of crystallography: the *space group* types and their corresponding *Wyckoff sets*. A complete review about these concepts can be found in [10]

The symmetry of the positions of atoms in a crystal is described by its space group. The translation symmetry is present into every space groups, because crystals have infinite translation periodicity at nanoscale. The Wyckoff set is position of the atom into the unit cell, which is the smallest volume which tiles the space by translation symmetry. We show that there exists an analogy between crystals and modular lattice systems. In existing lattice modular system, if we consider all the possible configuration of interconnected modules in a discretized coordinate system, the set of possible positions of the connectors forms a position field which has symmetry that can be described by a space group. Moreover, all the mobility axes of the modules also coincides with the geometric elements of the space group. Therefore each existing lattice modular robot correspond to a space group, and the position of its connectors is described by their corresponding Wyckoff sets. Only direct displacement symmetries (no inversion or reflexion) are needed for robotic systems, thus only a subset of the space groups are used, the so called 65 *chiral space groups* or *Sohncke groups*.

Our approach permits to define precisely lattice modular systems. It allows to classify them and easily see if different

TABLE I

CLASSIFICATION OF SOME LATTICE SYSTEMS. FOR EACH SYSTEM WE GIVE (1) ITS SPACE GROUP IN HERMANN-MAUGUIN NOTATION, (2) THE POSITION OF ITS CONNECTOR IN THE UNIT CELL GIVEN IN THE STANDARD WYCKOFF SETS NOTATION (SEE [10]), (3) THE ROTATIONAL SYMMETRY OF ITS CONNECTOR AND (4) THE DIRECTION OF THIS ROTATION AXIS. FOR THE TELECUBE THREE ROWS CORRESPOND TO THE SAME WYCKOFF SET BUT WITH DIFFERENT PARAMETERS.

Lattice modular system	Space group	Connector		
		Wyckoff set	rotation symetry	orientation
M-TRAN[1]	F432	e	4 fold	1,0,0
3D Unit[5]	F432	e	none	not applicable
3D Universal	F432	e	4 fold	1,0,0
Molecule[4]	F432	e	4 fold	1,0,0
Atron[6]	F432	g	none	not applicable
		h	none	not applicable
I-Cube[2]	P432	e	4 fold	1,0,0
Telecube[3]	P1	a	none	not applicable
		a'	none	not applicable
		a"	none	not applicable

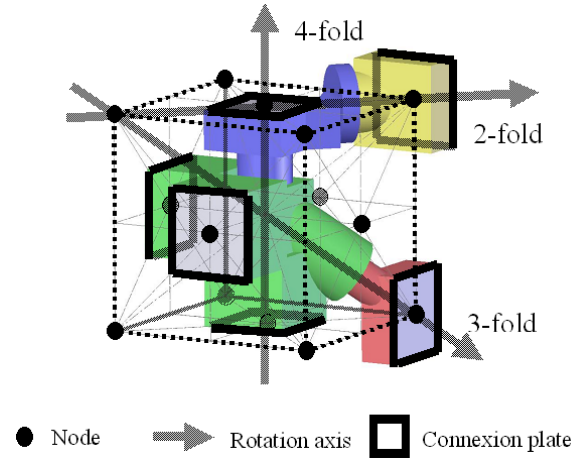

Fig. 1. Construction of a lattice module in space group F432 with face-centered cubic cell. The module has four bodies, six connectors and three actuators. The connection plates are in special position on the nodes and have 4-fold symmetry. The three actuators have 2-fold, 3-fold and 4-fold rotation axes corresponding to geometric elements of the space group, therefore this module has $2 \times 3 \times 4 = 24$ discrete configurations.

systems may be compatible. It also help the design of new lattice systems because the possible positions of mobility axes and connectors are discretized (example in figure 1), so as the orientation of the connectors and the state of actuators. Furthermore we give constraints between the connectors positions, orientation and the mobility axes to design reconfigurable lattice systems.

REFERENCES

[1] S. Murata, E. Yoshida, A. Kamimura, H. Kurokawa, K. Tomita, and S. Kokaji, "M-tran: self-reconfigurable modular robotic system," in *IEEE/ASME Trans. Mech. Vol. 7, No. 4*, 2002, pp. 431–441.

[2] C. Unsal and P. Khosla, "Solutions for 3-d selfreconfiguration in a modular robotic system: implementation and motion planning," in *Sensor Fusion and Decentralized Control in Robotic Systems III*, 2000.

[3] J. W. Suh, S. B. Homans, and M. H. Yim, "Telecubes: mechanical design of a module for self-reconfigurable robotics," in *IEEE Int. Conf. on Robotics and Automation (ICRA)*, 2002.

[4] K. Kotay and D. Rus, "Locomotion versatility through selfreconfiguration," in *Robotics and Autonomous Systems*, 1999.

[5] E. Yoshida, S. Murata, S. Kokaji, K. Tomita, and H. Kurokawa, "Micro self-reconfigurable modular robot using shape memory alloy," *Journal of Robotics and Mechatronics*, vol. 13 no.2, pp. 212–219, 2001.

[6] M. W. Jorgensen, E. H. Ostergaard, and H. H. Lund, "Modular atron: Modules for a self-reconfigurable robot," in *Proceedings of 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Sept. 2004.

[7] D. G. Duff, M. H. Yim, and K. Roufas, "Evolution of polybot: a modular reconfigurable robot," in *Proc. of the Harmonic Drive Int. Symposium and Proc. of COE/Super-Mechano-Systems Workshop*, Nov. 2001.

[8] P. Will, A. Castano, and W.-M. Shen, "Robot modularity for self-reconfiguration," in *Proc. SPIE Sensor Fusion and Decentralized Control II*, Sept. 1999, pp. 236–245.

[9] N. Brener, F. Ben Amar, and P. Bidaud, "Analysis of self-reconfigurable modular systems. a design proposal for multi-modes locomotion," *IEEE Int. Conf. on Robotics and Automation*, 2004.

[10] *International Tables for Crystallography, Volume A: Space Group Symmetry*, ser. International Tables for Crystallography. Theo Hahn, 2002.