MODULAR ROBOTS AS DISTRIBUTED COMPUTERS OF THEIR OWN MECHANICAL STATE

Benoit Piranda[1], Pawel Chodkiewicz[2], Pawel Holobut[3], Stephane Bordas[4], Julien Bourgeois[1], Jakub Lengiewicz[5]

[1] Universite Bourgogne Franche-Comte, FEMTO-ST Institute, CNRS, France
[2] Faculty of Automotive and Construction Machinery Engineering, Warsaw University of Technology, Poland
[3] Institute of Fundamental Technological Research, Polish Academy of Sciences, Poland
[4] Faculty of Science, Technology and Medicine, University of Luxembourg, Luxembourg
[5] Institute of Fundamental Technological Research, Polish Academy of Sciences, and Faculty of Science, Technology and Medicine, University of Luxembourg , Luxembourg

pholob@ippt.pan.pl

Modular robots are ensembles of simple robotic units, called modules, which can form complex structures by binding together. Modules can communicate with their neighbors, sense certain signals from the environment, store information and perform simple computations, move over other modules and attach to them. The movement of modules from one place to another within a robotic structure, called reconfiguration, is a major mechanism by which modular robots can change their overall shape. As an assembly of modules becomes more numerous, and the modules themselves smaller and simpler, the system starts to resemble an active, shape-changing material, possessing both computational and mechanical capabilities. Such futuristic, not-yet-made materials are frequently referred to as Programmable Matter.

Reconfiguration of modular robots poses a number of challanges. One of them is preservation of mechanical stability and integrity of a modular structure during reconfiguration. As modules change their positions in the structure, detaching from one place, then moving, and finally attaching at their destination, some inter-modular connections, which have limited strength, may become overloaded and break under gravity. Similarly, the movement of modules may shift the center of mass of the structure in such a way that the structure may lose stability and fall. Failures of this kind should be predicted before reconfiguration, preferably by the modular robot itself.

The present work addresses the problem of autonomous prediction by a modular robot of its possible future breakage or instability as a result of reconfiguration. The assessment is performed collectively by the modules in a distributed fashion, with each module doing simple computations and exchanging information with its direct neighbors. A simple Finite Element model of a modular robot is used, with pieces of the model data and state variables stored locally in each module's memory. The system is augmented by considering unilateral contact conditions between support modules and the ground, allowing the method to cope with the problem of stability as well. A simple iterative technique, the weighted Jacobi scheme, is employed to solve the resulting system of equations. Slow convergence of the weighted Jacobi method can be significantly improved by using a distributed Conjugate Gradient solver, although at the cost of difficulties with handling contact conditions.

The proposed method is verified in the modular-robot simulator VisibleSim, and on the robotic hardware Blinky Blocks. Although the focus is on cubic modules attached side to side, the method can also be applied to other shapes and arrangements of modules.