Molecubes: An Open-Source Modular Robotics Kit

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The appeal of modular robotics is in their potential versatility, robustness, and low cost of manufacture. These primary advantages, however, have yet to be fully realized [1]. Due to demanding level of expertise and a prohibitively high cost of fabrication and operation, majority of current research in modular robotics is limited to specialized labs at few select universities. We suggest that by making modular robots available to greater numbers of researchers, enthusiasts, and hobbyists we remove barriers to entry and accelerate progress of the field. With this goal in mind, we present a low cost, ruggedized and expandable open-source modular robotic system. In this paper, we describe the structure and properties of the modular robots, electrical and mechanical module interface, communications specifications, open source PC interface for visual design and control of modular system, examples of extension robotic modules and prospective applications. We propose this design as a platform for future community customization and further development, and expect that the ease of its acquisition and use will help grow the community of modular robotisists and generate new ideas and applications for the field. The designs of Molecubes and the interface software will be freely distributed through a dedicated user-group website at http://www.molecubes.org that we are currently developing.

Introduction

The field of modular robotics aims to revolutionize modern conventional robotics and industrial automation by producing a set of modules capable of forming a variety of robots of different shapes and functionalities each performing equally well or better than a conventional robot dedicated to one specific task. Such successful systems are yet to be demonstrated: Current modular robotics research still requires high entry level of expertise in robotics, engineering, and computer science. Moreover, over the recent two decades research in modular robotics has remained quite expensive: If one module is constructed at a cost of a car, and the usable set of modules can only be produced at a cost of a house [2], only few wealthy universities and research labs will be able to afford research in this area.

On the other hand, as concluded by most researchers in the field [1], one of the major challenges that limits the public interest to the area of modular robotics is the lack of demonstrable “killer application” where modular technology could, beyond doubt, prove superior to the conventional robotics. Several attempts have been taken to find an answer to this challenge inside of the modular robotics community, while attempts of reaching outside are complicated by limited physical robot or design availability, expense of construction, or insufficient level of end-user expertise.

In this paper, we present *Molecubes*, a low-cost simplified and ruggedized reconfigurable modular robotic platform that is relatively easy to manufacture, assemble, and operate for a hobbyist user. With the introduction of this system, we aim to encourage more researchers and hobbyists to undertake practical research in the area of modular robotics, thus broaden our community and elicit new ideas and insights into the future of the field, and develop new applications. We propose to use Molecubes as an expandable robotic platform and invite any new developments and enhancements that may come from the community of volunteer users and developers.

The salient module characteristics are given in Table 1, and material cost estimates are given in Table 2. In the following sections, we present the mechanics of the robot, module interface design, controller and communication architecture, the software providing visual interface for modular robotic design, simulation and control, and a few examples of prospective uses of the modular system.

Molecube Mechanics

The design of a module is inspired by our earlier successful design that was used to demonstrate physical robotic self-replication [3, 4]. The original Molecube design of 2004 has been miniaturized, simplified, and ruggedized.

Table 1. Molecube swivel module specifications.

Mechanical	
Dimensions (L x W x H)	66 x 66 x 66 mm
Weight	200 grams
Torque, max	49.5 kg-cm
Rotation	Continuous 360°
No-load speed, max	100 deg/sec (17 rpm)
Shells structural material	Printed ABS plastic
Swivel axis bearing	Single, thin section, X-type
Actuator type	Robotis AX-12 or AX-12+
Drive type	Spur gearbox
Overall reduction ratio	1 : 762
Back-drivable	Yes
Robot Interface	
Mechanical interface	4-way sym. Pin-to-Socket
Module retention method	Interference fit
Insertion / separation axial force for interference fit	~200 N
Reconfigurability	Manual, external
Continuous current capacity of the power supply bus	8 A
Power	
External DC power supply	12...24 VDC
Current consumption at max torque	1 A
Sensing	
Module orientation relative to attached modules	Yes
Servo position	Yes
Servo temperature	Yes
Controllers	
North half controller	ATMega16
South half controller	ATMega16
Servo controller embedded in AX-12	ATMega8
Communications	
Internal serial protocol	Half Duplex Asynchronous, 8 bit, 1 stop, no parity
Internal serial link	TTL level, Rx and Tx multiplexed on single wire
Internal serial link speed	57.6 kbps (up to 1 Mbps)
Inter-module 1-wire protocol	Modified Dallas 1-wire
Inter-module 1-wire bus speed	1.6 kbps

Each robot, as shown in Fig. 1, has a shape of a cube with rounded corners and comprises approximately two triangular pyramidal halves connected with their bases so that their main axes are coincident. These cube halves are rotated by the robot motor about a common axis relative to each other. Each of the six faces of a robot is equipped with an electromechanical connector that can be used to join two modules together. Symmetric connector design allows 4 possible relative orientations of two connected module interfaces, each resulting in different robot kinematics. The major mechanical parts of the module are shown in Fig. 2.

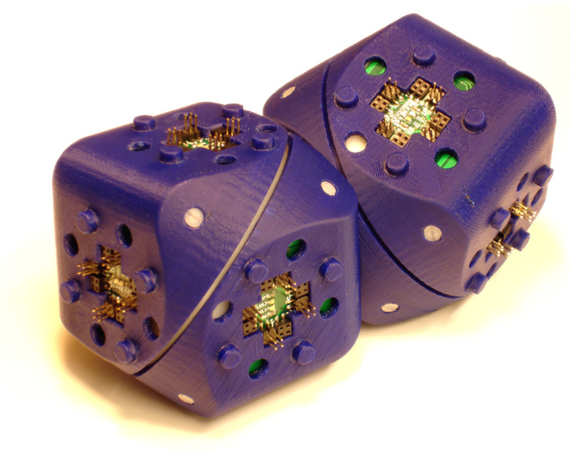

Figure 1. Two Molecubes joined together.

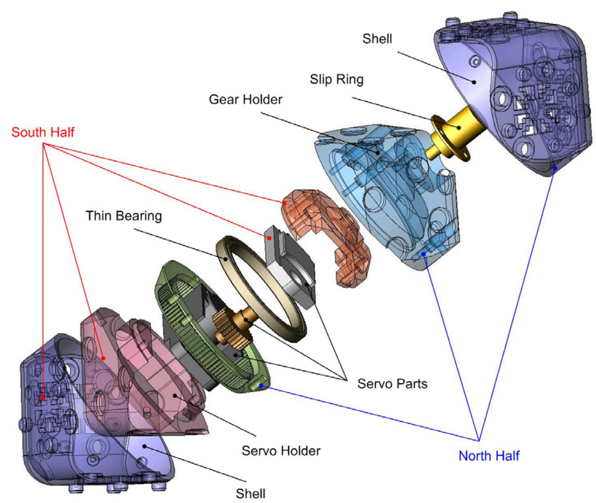

Figure 2. Main mechanical components of a Molecube.

Each Molecube has six major structural parts that are shown translucent in Fig. 2 and can all be manufactured from ABS plastic using the available design files and a fused deposition rapid prototyping machine, for example, Dimension SST or similar.

The remaining components are standard stock parts: the AX-12 servo, thin section X-type bearing and the electrical collector to enable continuous

Table 2. Molecube actuator module material costs estimate for a fabrication run of 50 pieces.

Part Description	Cost
Fabrication of custom rapid-prototyped structural ABS parts (material cost)	$50
Fabrication and assembly of custom interface printed circuit boards, electronic components	$120
AX-12 servo motor	$45
KAA17XLO thin section precision ball bearing	$40
AC6373-12 slip ring capsule	$94
Total Estimate:	$349

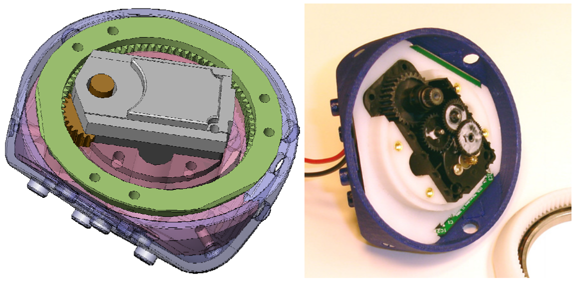

Figure 3. Meshing of a modified AX-12 servo motor with the Molecube internal gear. AX-12 front wall is removed.

module rotation. The AX-12 servo occupies the largest volume inside of the module. Its body dimensions limit the smallest possible dimensions of the Molecube. To make the module as small as possible, and improve the torque transmission from the servo to the robot halves, the servo was modified as shown in Fig. 3. The front wall of the servo is removed, and the output internal gear of the Molecube is meshed directly with the output spur gear of the robot that is located inside of the servo body. This type of meshing allows the servo output shaft to be supported in the bearings on both sides of the torque transmission point, thus reducing the gear deflection, wear, and the chance of gear disengagement under load.

Robot Interface

Both mechanical and electrical interfaces are pin-and socket type as shown in Fig. 4.

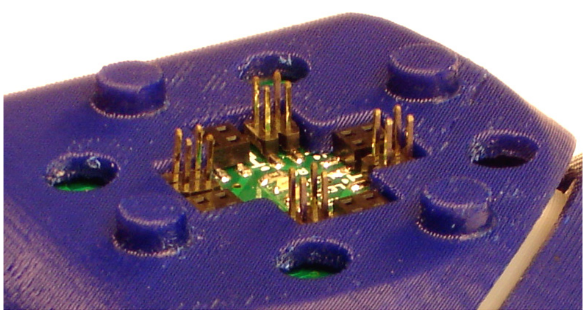

Figure 4. Molecube electromechanical interface.

High mechanical retention force between two joined modules is provided by the interference fit of the eight interlocking pairs of ABS pins and sockets. 16 pairs of electrical pins and sockets provide 8 redundant channels of electrical connection for passing the ground, power, and communication signals, as well as dedicated processor inputs and outputs for robot orientation sensing relative its neighbor modules, as shown in Fig. 5.

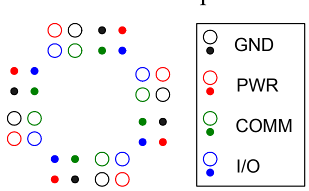

Figure 5. Molecube electrical interface terminal-to-signal assignment.

Module controller and communication

Each of the two halves of every robotic module is equipped with one Atmel Mega16 microprocessor. Both microprocessors are connected to the global TTL level half duplex RS232 bus, to which all other joined actuator, controller, and other add-on robotic modules are connected. Inside of the robot, there is another communication line of the same type, to which both processors and AX-12 servo are connected. Any of the two microprocessors can be used to control the servo motor, however both are necessary for correct and complete sensing of the module orientation relative to its neighbors.

The schematic of inter- and intra-module communications is given in Fig. 6. For both internal and external half-duplex RS-232 busses, the speed of communication is programmable up to 1 MBps.

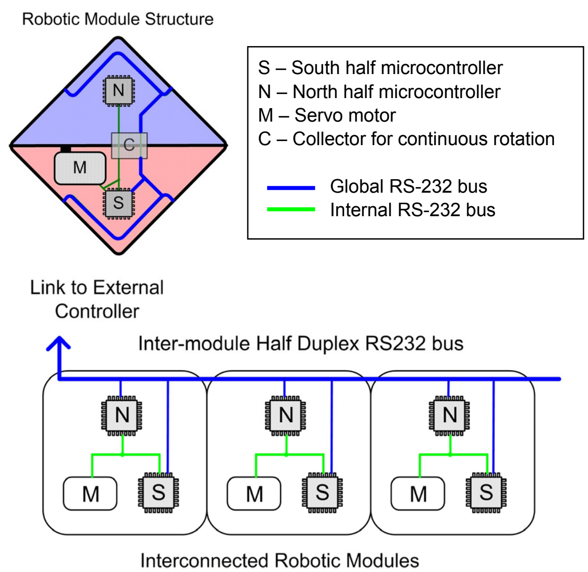

Figure 6. Internal and external module communication schematic.

All the necessary firmware for the embedded microprocessors will be provided to the user community through the dedicated user-group web site.

Communication with the user PC will be implemented using a separate dedicated controller module. The controller module will not have any motion capabilities, instead it will be equipped with a more powerful microprocessor, for example, 16/32 bit ARM Olimex LPC-H2148, that will support higher level control functions, such as higher level robot behaviors, behavior storage and exchange with the PC through either wireless, Bluetooth or USB connection.

Visual design, simulation and control

We have developed a visual software interface that will provide the users with the means of initial robot design and simulation before the actual robot is built. Alternatively, it can also be used to identify the structure of assembled robots and for behavior design automation. The screenshot of its visual interface is given in Fig. 7.

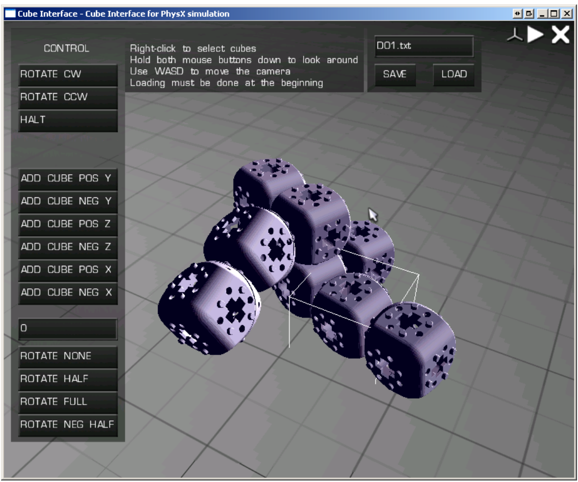

Figure 7. Visual interface for Molecube motion design, simulation and control

This interface uses AGEIA PhysX physics engine to simulate robot motion and OGRE open source graphics engine for graphics rendering. This graphical interface provides users with intuitive means of robot design, control, and testing.

Extension modules, prospective applications

We envision the Molecube system to be easily expandable with a variety of modules providing additional functionality, all equipped with a uniform electromechanical interface as described earlier and supporting 1-Wire communication bus. A variety of multifunctional robots that can be built using the generic Molecube modules plus a wheel module, a gripper, a base and a camera phone (as, for instance, an external controller) is shown in Fig. 8.

So far, we have constructed three prototype Molecube modules. The frames of the movie showing the first cantilever manipulation of a 3-cube long robot are given in Fig. 9.

Conclusions

We presented *Molecubes*, a ruggedized manually reconfigurable modular robotic platform designed to be accessible to broad range of volunteer robotisists ruggedness of this new modular system interested in

Figure 8. Examples of robots built with auxilliary functional modules

Figure 9. First 3-module cantilever test.

modular robotics. We believe that relative ease of acquisition and built-in simplicity of Molecubes will promote growth of the modular robotics community and bring to light new ideas, designs and applications, thus benefiting the field overall.

Acknowledgments

Blueprints, source code and circuitry are available at http://www.molecubes.org. This research was funded in part by Microsoft Research, Embedded Systems and Robotics program, and by Festo AG, Learning systems program. We thank Dr. Stewart Tansley and Dr. Hermann Klinger for their support.

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