Tangible Interaction with 3D Printed Modular Robots through Multi-Channel Sensors

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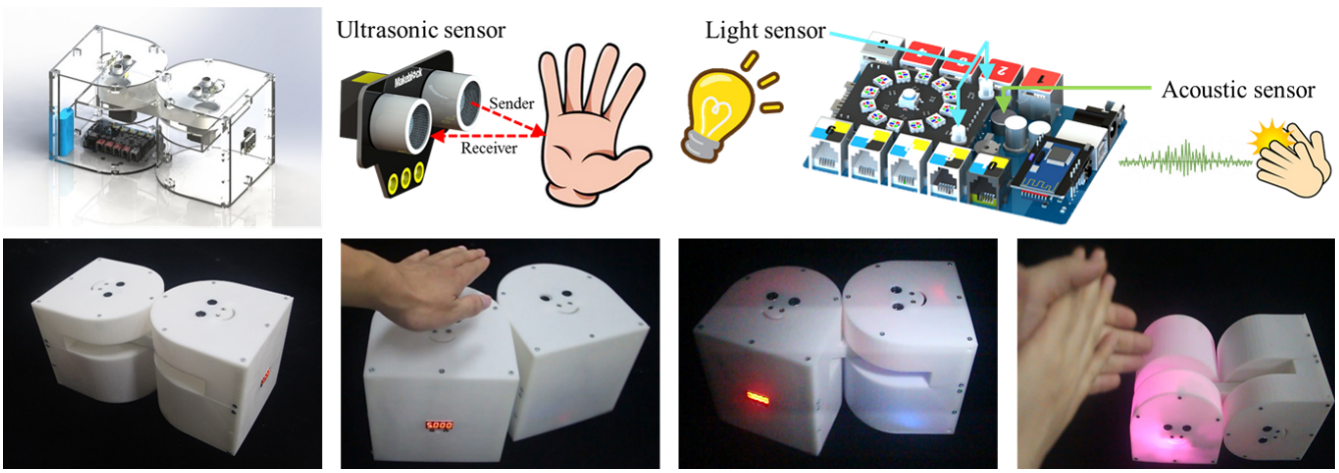

Figure 1: Modular robots consisting of edge-hinged modules can provide rich degree-of-freedom in rotation (the leftmost column). We introduce tangible interaction through three perception channels (haptics, visual and auditory) into the robots. A user study shows that students can effectively improve their spatial reasoning skills after interacting with these robots.

CCS CONCEPTS

• **Human-centered computing** → **User studies**; **Interaction devices**;

KEYWORDS

Tangible interaction, modular robot, 3D printing, spatial ability

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1 INTRODUCTION

Tangible interaction with customized products integrating sensors and actuators recently grows into an interdisciplinary research area in computer graphics and human-robot interaction (e.g., [Groeger et al. 2016; Yu et al. 2018]). In this paper, we introduce tangible interaction into 3D printed modular robots. Our user study demonstrates that interacting with our robots can effectively improve human spatial ability, which plays an important role during a person's development in science, technology, engineering or math (STEM).

Reconfigurable modular robots (RMRobots) are constructed by modules. Each module is physically independent and can be regarded as a robotic primitive, which encapsulates all on-board components for building a robot (e.g., [Yu et al. 2017]). RMRobots can change their shape and functionality according to the variation of working environment and tasks.

Our work is based on an important observation: in RMRobots that make use of edge-hinged modules (Figure 1), rich degrees-of-freedom (DOFs) in rotation can be provided. An edge-hinged module (EHModule) consists of two edge-linked semi-cylindrical cubes and each cube can rotate independently. Two or more EHModules can be connected via a mechanical or electromagnetic connection. Therefore, more rotation DOFs can be further provided.

By introducing tangible interaction with the help of off-the-shelf actuators and sensors, we can easily fabricate them by 3D printing. Our study applies EHModules as a useful tool for the training of spatial ability. Spatial ability (a.k.a. visuo-spatial ability) is a category of human capacity to understand, reason and remember the spatial relations among objects [Carpenter and Just 1986]. Spatial ability of children or teenagers significantly predicts their attainable achievement in STEM [Shea et al. 2001]. Two widely used measures of spatial ability are mental folding and mental rotation [Harris et al. 2013]. By utilizing EHModules, we pay attention to mental rotation, which is the ability to rotate mental representation of 3D objects in space quickly and accurately, while the object's features remain unchanged.

2 PHYSICAL PROTOTYPE

In our design, each EHModule has two semi-cylindrical cubes connected by a link, and each cube can rotate independently. To implement and encapsulate these functions, the on-board components in each EHModule include a MG995 servomotor as the actuator, an Me Auriga's mainboard with ATmega2560 CPU as control circuit, and a Li-Po7.4v 2600mAh battery. Interactions with human in three perception channels are provided as shown in Figure 1:

- Haptic: a Me Ultrasonic sensor v3.0 was installed to detect the distance between human parts (e.g., hands) and the robot;
- Auditory: the Me Auriga's mainboard provided an on-board acoustic sensor to detect sound intensity in the environment;
- Visual: the Me Auriga's mainboard provided an on-board light sensor to detect the change of environmental light, and a KEM-3461-BSR 7-segment LED display was installed to show the distance detected by the ultrasonic sensor, the light intensity measured by light sensor or sound intensity measured by the acoustic sensor.

All above electronic components are off-the-shelf, and the cover of an EHModule and its interior supporting structures are fabricated by 3D printing.

3 INTERACTION WITH EHMODULES

Users can interact with EHModules in three ways:

- Haptic: a user can move her/his hands closely to the EHModule and the ultrasonic sensor can detect the distance from the hand. One cube will be rotated around the other fixed cube according to the measured distance. The closer the distance to the hand is, the larger the rotation angle is.
- Auditory: a user can clap hands and the number of claps is used to control the rotation of the EHModule.
- Visual: a user can change the environmental lighting condition (e.g., turn on/off a desk lamp or a flashlight, or block the light source by hands) to control the rotation of the EHModule.

See accompanying video for more details.

4 USER STUDY

We recruited 22 undergraduate and graduate students (11 males and 11 females), whose average age was 24.0 years ($range = [21, 31]$, $SD = 3.52$). First, each participant went through a 20-item Purdue Visualization of Rotations (ROT) test for evaluating his/her spatial ability. Participants were partitioned into two groups (namely experimental group and control group), such that the ROT test scores of two groups were ensured at the same level.

Then each participant completed three consecutive sessions: pre-test, training session and post-test. Both pre-test and post-test consisted of 10 successive transformation tasks. All participants were instructed to complete both tests as quickly as possible on the premise of ensuring the correct rate. Task performance between two tests was expected to examine the effect of training.

During the training session, the experimental group was required to interact with EHModules for becoming familiar with the rotation rules in EasySRRobot, while the control group was required to learn by reading an instruction document. The training time was kept the same for both groups, i.e., 20 minutes.

In the pre-test and the post-test sessions, the average time (in seconds) that a participant spends to complete a transformation task, called TTC, was recorded. After interacting with EHModules, the TTC of experimental group decreased 37% and the average rate of correctness increased 17%. As a comparison, after reading the paper instruction, the TTC of control group only decreased 19% and the average correct rate only increased 3%. These experimental tests demonstrate that the training by interacting with EHModules can effectively improve the performance of participants' skill (in both speed and correctness) in transformation tasks.

5 CONCLUSION

In this paper, we introduce various functions of interaction via visual, auditory and haptic sensors, into modular robots. By assembling with off-the-shelf electronic components into a shell with supporting structures fabricated by 3D printing, a customized modular robot with tangible interface is ready to use. An elaborated user study indicates that interaction with this customized robot can effectively improve the performance on a task relevant to spatial ability.

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REFERENCES

P. A. Carpenter and M. A. Just. 1986. Spatial ability: An information processing approach to psychometrics. In *Advances in the Psychology of Human Intelligence*, Vol. 3. Hillsdale, NJ: Lawrence Erlbaum Associates, 221–252.

Daniel Groeger, Elena Chong Loo, and Jürgen Steimle. 2016. HotFlex: Post-print Customization of 3D Prints Using Embedded State Change. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI'16)*. 420–432.

Justin Harris, Kathy Hirsh-Pasek, and Nora S. Newcombe. 2013. Understanding spatial transformations: similarities and differences between mental rotation and mental folding. *Cognitive Processing* 14, 2 (2013), 105–115.

Daniel L. Shea, David Lubinski, and Camilla P. Benbow. 2001. Importance of Assessing Spatial Ability in Intellectually Talented Young Adolescents: A 20-Year Longitudinal Study. *Journal of Educational Psychology* 93, 3 (2001), 604–614.

Minjing Yu, Yong-Jin Liu, and Charlie C.L. Wang. 2017. EasySRRobot: An Easy-to-Build Self-Reconfigurable Robot with Optimized Design. In *IEEE International Conference on Robotics and Biomimetics (IEEE-ROBIO '17)*. 1094–1099.

Minjing Yu, Yong-Jin Liu, Guozhen Zhao, Chun Yu, and Yuanchun Shi. 2018. Spatial Ability Improvement by Tangible Interaction: A Case Study with EasySRRobot. In *Proceedings of the 2018 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '18)*. ACM, LBW013:1–LBW013:6.