ModBot: A Tangible and Modular Making Toolkit for Children to Create Underwater Robots

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Abstract
Underwater robot is essential equipment for exploring the marine environment. It is important that children get exposed to these technologies as earlier as possible, especially there is a high demand for developing expertise and awareness in the underwater robot. Although examples of making toolkit for children currently exist, few focus specifically on integration with the water environment. In this paper, we explore the making toolkit, ModBot, which can be applied to the water environment. The hardware was developed using electronic, counterweight, and shape modules that can be manipulated to build underwater robots. The software application allows children to learn concepts and receive construction feedback. This paper presents the system design of ModBot, the design rationale, and a user study for the usability of ModBot. Our system is expected to spark children's interests and creativity of underwater robots, and foster their understanding of the water environment.

Author Keywords
Underwater robot; making toolkit; modular robot; user interface; children; water environment.

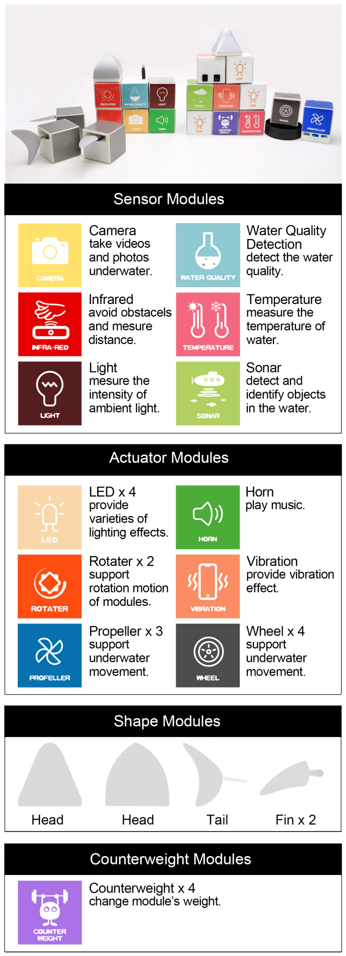

Figure 1: ModBot prototype includes 30 modules: 6 sensor modules, 15 actuator modules, 5 shape modules and 4 counterweight modules.

CSS Concepts

• **Human-centered computing~ Human computer interaction (HCI)**; User interface toolkits;

• **Human-centered computing~ Interaction design**; User interface design;

• **Applied computing~ Education**; Computer-assisted instruction.

Introduction

The underwater robot is a vital tool in the field of marine engineering to explore the ocean environment and ocean resources [16]. Underwater robots cover the knowledge and technologies of electronics, computer, mechanics, and so on, and it is an excellent medium to carry out STEM education. At roughly kindergarten age, children demonstrate increased attention, self-direction, and logical thinking [13]. Children as young as 4 years old can successfully build and program simple robotics projects while learning a range of engineering and robotics concepts in the process [2, 12].

Robot construction toolkits have shown promise in attracting underrepresented groups to STEM, broadening perceptions of computing, and empowering users to create self-expressive and personally meaningful computational designs [4]. Compared with land-based robot construction toolkits, underwater robot toolkits provide children with more interactive experiences and learning opportunities.

Firstly, when children build underwater robots, they need to consider factors of water environment, such as water depth, buoyancy, pressure, temperature, and water quality, which give them opportunities to understand and explore the water environment. Secondly, there are differences between the working principles of underwater robots and that of land robots, like waterproof, propulsion, and balance requirements. Children have little access to these experiences and technologies in their daily lives, and these experiences are also difficult to obtain from existing robot making toolkits. Besides, the existing underwater robots require rich experience, knowledge, and technical background of users. The machinery, communication, driving, and navigation of underwater robots all make it challenging for children to understand and play.

In this paper, we present ModBot (Figure 1), a tangible and modular toolkit to help children ages 5-10 understand the knowledge of underwater robots, like the *Ballast, Propulsion, Sensors* concepts. ModBot consists of a set of electronic modules, counterweight modules, shape modules, and a tablet application. Although examples of modular robot toolkit for children currently exist, these systems focus primarily on fundamental ideas from robotics, computer science, and engineering [11]. Few have explicitly focused on assisting children to explore underwater robots and water environments. The main contributions of our work are: 1) a modular making toolkit for children to explore underwater robotics and water environment; 2) a design rationale for using modules-based tangible interfaces for children's underwater robot construction system; and 3) the specific design and development behind the ModBot toolkit.

Related Work

Robot education, new media literacy, and program are critical 21st-century requirements, and they are increasingly promoted to younger age groups. Robotics

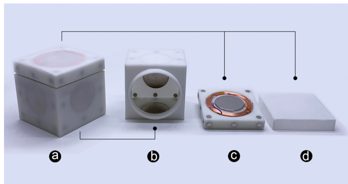

Figure 2: The structure of ModBot module: (a) the standard module; (b) the inner faces of the module are inlaid with magnets; (c) one face is used for wireless charging; (d) the cap of wireless charging face.

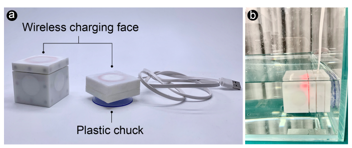

Figure 3: Wireless charging: (a) the charging platform (b) the charging platform is placed on the glass wall by chuck, and two charging faces are joined together through magnets.

Figure 4: Water environment: water in a glass tank.

construction toolkits that are programmable allow children to understand ideas from robot, computer science, and engineering while simultaneously providing opportunities for expression through the creation of projects that can move around and respond to the environment through sensors [11].

Evidence, both anecdotal and research-based, suggests that playing with construction modules like LEGO, can foster creativity, math skills, and mechanical aptitude [10]. Randi Williams developed "PopBots" [14, 15], where preschool children trained and interacted with robots to learn AI concepts. Topobo [6, 7] was designed to model both the form and motion of the dynamic structural system. Children can snap the modules together to form models of animals, regular geometries, or abstract shapes. With this system, children can learn about movement and animal locomotion. However, during those making processes, environmental factors were not taken into account, and all modules can only be played on land.

Underwater robotics is by far the best option to explore the water bodies. The recent advances in underwater robotics are opening opportunities for the researchers and industries [1]. Some of the widely used sensors in underwater robotics are depth sensor, proximity sensor, roll and pitch sensor, angular rate sensors, three-axis gyrocompasses, etc. [3]. Santhosh Ravichandran [8] presented an underwater robot with two reconfigurable and detachable swimming modules that could offer both maneuverability and propulsive efficiency. M. Sani proposed underwater vehicles combining the features of both ROV (remotely operated vehicle) and AUV (autonomous underwater vehicle) technologies [9]. However, all of these robot designs were difficult and challenging for children to understand and play.

ModBot builds on work in modular construction kit and underwater robot, where the entire construction is easy to manipulate. It simplifies literacy, programming, and mechanical construction, and allows children to design their underwater robots at low cost. We hope this system can inspire children to create underwater robots according to their own stories and stimulate them to perceive and learn the knowledge of underwater robot and water environment.

ModBot Toolkit System

ModBot toolkit consists of two parts, hardware and software. The hardware includes modular cubes with different functions, and the software provides the functions of display, program, and guidance. The water environment in our system is water in a glass tank, 90cmX45cmX45cm (Figure 4). Children can create underwater robots with modules, control the robots on the software platform, and play with the robots in water.

Learning with ModBot

The main learning goal is to teach children about the electronics that make up underwater robots and their basic principles for construction. ModBot system can deliver the following knowledge to children:

- Basic concepts of underwater robots: waterproof, balance, ballast, and propulsion. Unlike robots on land, children will have to learn the waterproof concept of underwater robots. Modules have similar weights, and the symmetrical shape (weight balance) allows the robot to keep balance in the water. Children can change the weight of counterweight modules to adjust the robot’s position in the water (surface, medium, and bottom). Also, they can learn

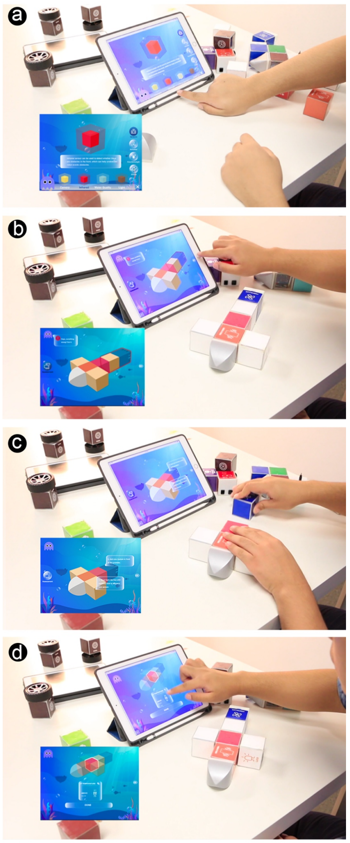

Figure 5: Software app of ModBot: (a) learn concepts of modules; (b) build an underwater robot; (c) asses the balance of robot and give guidance; (d) program and control modules.

the propulsion ways in water through the propeller modules.

- Features of water environment. Children can experience features of water environment, such as temperature, depth, buoyancy, and water quality. It can encourage them to think about how these environmental factors affect the construction of underwater robots.
- Construction principle of underwater robots. Children can learn the functions of each module on the software app. Combine sensors, actuators, and other modules to achieve different applications of underwater robots, which can train their logic ability.

Design goals

- The water environment for play is easy to prepare and safe for children.
- The approach of assembling modules is simple and fast.
- Providing a guiding channel for construction.
- A multimodal feedback approach including animations, letters, and audios to support children play and learn with this system.

Magnet-based modules

We have now designed and built 30 modules, including 6 sensor modules, 15 actuator modules, 5 shape modules, and 4 counterweight modules (Figure 1).

- Sensor modules: camera, water quality detection, infrared, temperature, sonar, and light sensor.
- Actuator modules: LED (x4), rotater (x2), horn, vibration, propeller (x3), wheel (x4).
- Shape modules: head (x2), tail, fin (x2).
- Counterweight modules (x4) can help change the weight of robots and adjust the balance and buoyancy.

All modules are waterproof by using thread and silicone pad. The standard module is a plastic cube with a size of 50mm and a weight of 125g. Magnets are embedded in the module's inner faces, which allow modules to be assembled together effortlessly (Figure 2). The faces are covered with stickers, and the icons and text information are easy for children to understand (Figure 1).

Wireless charging

We established a charging platform. Each electronic module contains a lithium battery (3.7v, 1500mAh), and one face is used as the site of charging (Figure 3a). When the module's charging face contacts with the charging platform, the module would be charged. The charging platform can be placed on the glass wall through the chuck, and modules can also be charged in the water (Figure 3b).

Software application

We designed a software application based on a tablet. Users can learn concepts of modules on the software interface and drag modules to build their underwater robots (Figure 5a). The weight of each module is recorded, and the system can assess whether the robot can keep balance according to the selected modules (Figure 5b) and displays with animation. Users can also turn to the app for constructed guidance on balance adjustment (Figure 5c). Modules can be programmed on the software platform, like the color of LED (Figure

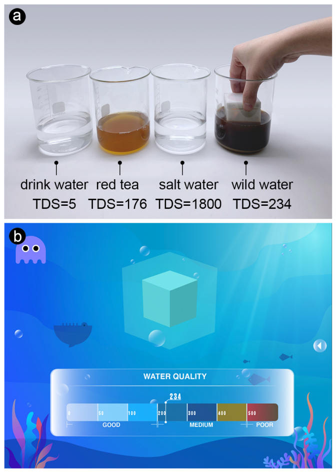

Figure 6: Application of the water quality detection module: (a) detect the Total Dissolved Solids (TDS) values; (b) the app can display the results.

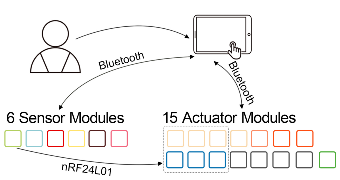

Figure 7: Communication approach.

5d). The app also displays the information detected by modules. For example, the water quality detection module can roughly measure the quality of liquid, and the app will give the result (Figure 6). Users can also create interactions of different modules on this app, like when the water temperature is above 29 degrees, the robot will turn on the yellow light.

Communication

Each electronic cube has an nRF24L01 module and a Bluetooth communication board. nRF24L01 module can make one sensor connect with six actuators. On the software app, users can design the interactions of sensors and actuators. Data transmission between modules and the tablet can be achieved through Bluetooth (Figure 7).

User Studies

We conducted workshops at the local children center to examine if the ModBot toolkit is engaging and usable for children, and find out if children can understand the concepts of modules and apply modules to build underwater robots. This study involved 15 children aged 5-10 (M=7.73, SD=1.69). Participants were recruited via the children center with the consent of their parents. All children were asked previous experience with underwater robots, and more than 90% of the participants did not learn, see, or play with the underwater robots.

The study lasted nearly 2 hours and included: a 15 mins pre-study semi-structured interview, 20 mins introduction of ModBot toolkit, and 60 mins playing with ModBot. There were two of our researchers and one staff from the children center to help facilitate the workshops. We set up two tasks:

- Task 1: Design an underwater robot that can shoot video and automatically turn on the LED when the environment light is not enough.
- Task 2: Design an underwater robot with the functions of task1, but also need to swim in the water and avoid obstacles, and can detect the quality of water.

Results

Task 1. The modules that must be used in task 1 were camera module, light sensor, and LED (Figure 8a). 1 of 15 children failed the task. By observing and analyzing the recorded video, we found that 14 of 15 children could successfully select the right modules when they first constructed, and 1 child was wrong to use the infrared module as the light sensor. After finishing the assembling, children tried an average of 2 times to adjust the balance of robots, and 7 children followed the guidance of the app to adjust the balance. The average time they took to finish was 19.33 mins (SD=5.12). The results showed that children can understand the concepts of modules, and can build underwater robots to achieve simple interactions.

Task 2. Task 2 was more complicated than task 1. In task 2, children needed to use more modules: camera module, light sensor, LED, infrared or sonar module, water quality detection module, and propeller module (Figure 8b). 11 of 15 finished the task successfully. 4 children failed because of problems: 1) the photosensitive surface of the infrared module did not face the robot's heading direction, and the obstacle

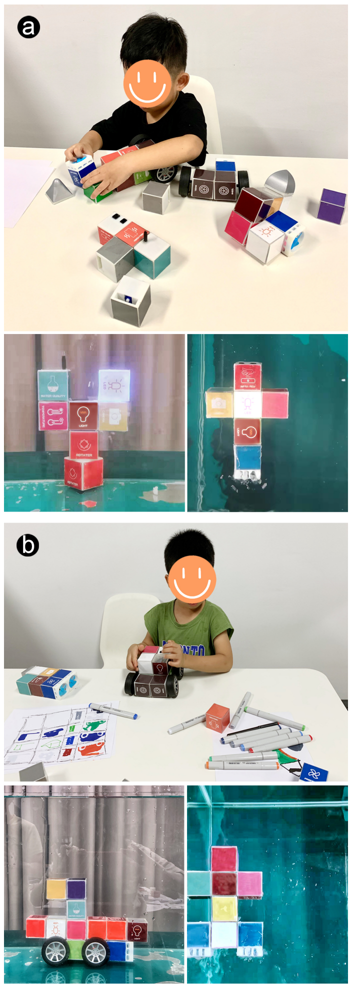

Figure 8: Underwater robots built by children. (a) task 1, *Coral* and *Ship*; (b) task 2, *Underwater Vehicle* and *Underwater Plane*.

avoidance function could not be realized; 2) the robot cannot keep balance in water; 3) failing to program the modules. 13 children turned to the software platform, and they made an average of 3.73 attempts to build the robot. It took them longer to finish task 2, with an average time of 34 mins (SD=5.61). As difficulty increased, children's success rates decreased, and they were more likely to use software platform for help. The results showed that the software platform could provide useful guidance on robot balance adjustment.

Overall, we found that children were very interested in the ModBot toolkit and had high engagement. They can understand the concepts of modules and can use them to build underwater robots.

Discussion and future work

Underwater robot is one of the indispensable tools for human to explore and develop the ocean. Children, as the new generation, are exposed to and learn about these high and new technologies in advance, which can make them participate in social development quickly and easily in the future. In this paper, we designed ModBot toolkit to help children improve their understanding of underwater robots and water environments. ModBot is a STEM-based approach that allows children to create underwater robots and interact on the software app. It conveys to children underwater robot concepts like ballast, propulsion, sensors, etc. and encourage them to explore applications of underwater robots.

Papert's theory of constructionism suggests that the best learning experiences occur when children are actively engaged in designing and creating things [5]. Through multiple builds and tests, children adjust the shape, counterweight, functions to create their robots. ModBot makes the learning experience interesting and operable. It allows children to learn and think in practice, which is conducive to improve the abilities of innovation, exploration, and independence. ModBot can also motivate children to pay attention to the water and ocean environment, like environmental protection and marine resources exploration.

However, ModBot still has some limitations, which we will have to address in the future. The current communication distance is limited and only supports communication within 1 meter. Moreover, the ModBot system has not been tested in open water and currently only supports working in shallow water environments. In the future, we will explore the use of underwater acoustic communication and test in complex water environments. We also displayed our toolkit prototype to HCI and educational experts and received valuable suggestions to include in our next iteration. At present, we have not tested children's learning results. We will conduct studies to evaluate children's interactions and learning outcomes with ModBot compared to traditional instructional approaches.

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