DupRobo: An Interactive Robotic Platform for Physical Block-based Autocompletion

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Abstract

In this paper, we present DupRobo, an interactive robotic platform for tangible block-based design and construction. DupRobo supported user-customisable exemplar, repetition control, and tangible autocompletion, through the computer-vision and the robotic techniques. With DupRobo, we aim to reduce users' workload in repetitive block-based construction, yet preserve the direct manipulatability and the intuitiveness in tangible model design, such as product design and architecture design.

Keywords: Robotic, Block assembly, Physical autocompletion.

Concepts: •Human-centered computing → Interactive systems and tools;

1 Introduction

Assembly blocks (e.g. LEGO and DUPLO) have been a popular type of toys over time. They are also widely applied in various creative processes, such as product design [Lofaro et al. 2009] and architecture design [Smithwick et al. 2017]. Different from sketching which is thought of as 2D visual design thinking, physical block building, with its emphasis on assembly and manipulation, ought to be considered 3D physical design thinking a more tangible, interactive way of exploring designs [Smithwick et al. 2017].

Research [Smithwick et al. 2017] showed that this type of hands-on prototyping platform can retain users interest and attention, promote design creativity, and facilitate team work. Unlike sketching, which involves marking a 2D flat surface, physical model making takes place in three dimensional space and involves different forms of material interaction, can further facilitating problem solving.

However, it is still confusing and tedious for non-experienced users to construct large physical models [Strobel 2010], and it is even more difficult to create new models from scratch. One reason could be that a large complicated model often involves many repetitive parts. For example, the Parthenon model contains multiple similar pillar structures, and the Great Wall model consists of many embattlements. On the other hand, it is observable that highly creative patterns can be generated through controlling the repetition of a primitive exemplar. The exemplar repetition, also known as autocompletion, has been widely supported in many 2D/3D design softwares [Kazi et al. 2012; Xing et al. 2014; Peng et al. 2017]. But interacting with a 3D model virtually can be far less intuitive than actually making the physical model [Ishii and Ullmer 1997]. In this research, we aim to reduce the manual workload in repetitive block assembly through physical autocompletion, yet preserve the direct manipulatablity and the intuitiveness in tangible modelling.

In this paper, we present DupRobo, an interactive robotic platform for tangible block-based design and construction. DupRobot supported user-customisable exemplar, repetition control, and physical autocompletion. As shown in Fig. 1, the setup of DupRobot consists of a Kinect sensor above the construction platform to track the user input (i.e. the exemplar building and the paper-based commands), and a robotic arm for automatic construction. Here we work only with the DUPLO blocks with a 2 2 arrangement of studs in the current prototype, to keep the problem computationally tractable. We didn't take the colors of the blocks as an input parameter, since our current main focus is to facilitate the physical structural autocompletion. While robotic assistants have been widely applied to many industrial domains to reduce the repetitive workload of human, e.g. component assembling, they were rarely used to facilitate tangible creative processes.

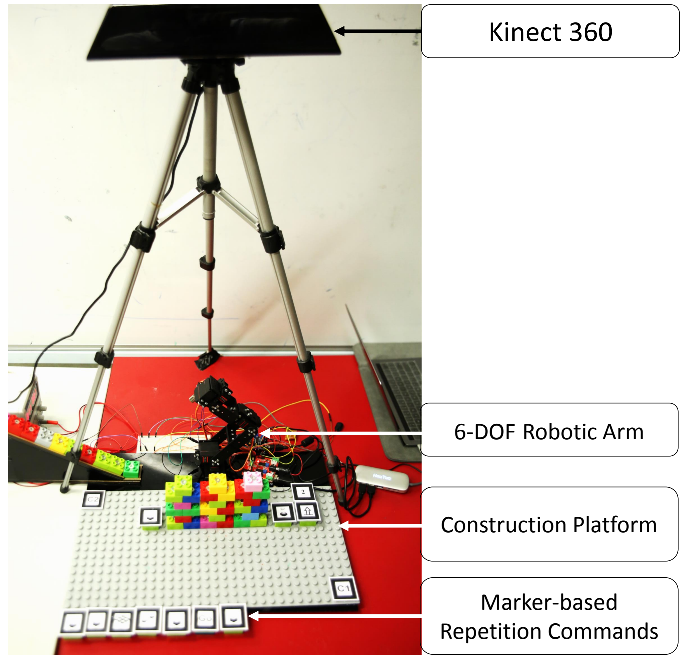

Figure 1: *DupRobo setup.*

Fig. 2 shows the processing flow of DupRobo. The user first constructs a physical block-based model as the physical exemplar. The exemplar building process is captured and tracked using the Kinect sensor above the construction platform on the table. The DupRobo system provides a set of paper-based commands for users to create the repetitive pattern, and controls the robotic arm to build the physical model. By repeating a physical exemplar, DupRobo facilitates users to physically create complex structures. Fig. 3 shows a list of examples constructed by DupRobo with various combinations of physical exemplars and paper-based repetition commands.Furthermore, the native support of assembling and disassembling in block-based construction allows users to modify the physical autocompleted model.

2 Related Work

DupRobo was inspired by the existing works on the 2D drawing autocompletion, the 3D block-assembly tracking, and the interaction

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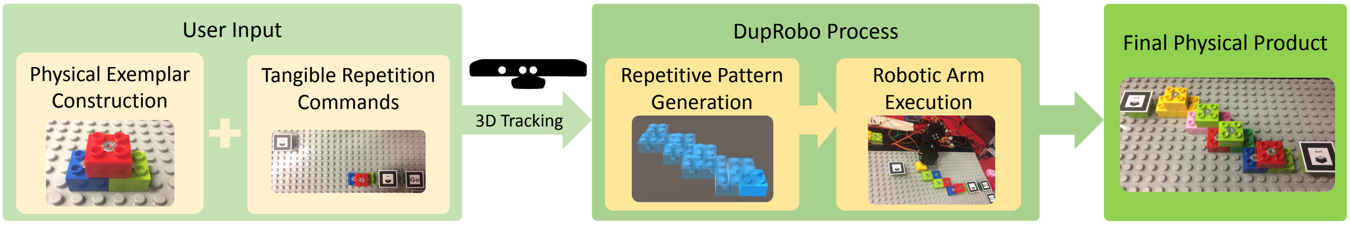

Figure 2: *System diagram of DupRobo.*

Figure 3: *Examples of physical exemplars and repetitive structures physically autocompleted by DupRobo.*

with robotic assistants.

2.1 2D Drawing Autocompletion

The research on automatic repetitions of visual patterns has been greatly advanced in recent data-driven methods [Kazi et al. 2012; Xing et al. 2014]. These works impose a list of sequential orders with the user-defined exemplars to be cloned to the desired output regions through various gestural commands, such as brushes. Similar autocompletion techniques were recently applied on 3D surface sculpting [Peng et al. 2017]. Although the autocompleted 3D virtual surface can be physicalised through 3D printing, it still requires users to edit the 3D model in the graphical user interfaces which could be less direct or intuitive than the tangible user interfaces. Taking one step further, DupRobo support the physical block-based modelling autocompletion with tangible commands.

2.2 Tracking and Generating Block Assembly

There has also been a series of research on tracking block-assembly procedures. Miller et al. [Miller et al. 2012] developed a Kinect-based system to track how a DUPLO model is built,with the assumption that the model always stays with its base on the table to reduce the tracking to 3 degrees of freedom (DOF). Gupta et al. [Gupta et al. 2012] presented a real-time system which can track an assembly process of Duplo blocks in 6-DOF. In DupRobot, similar to Miller et al., we assumed users build the exemplar on the table block by block, and tracked the building process using Kinect.

2.3 Robotic Assistant

Last but not the least, DupRobo is strongly inspired by the recent development in interacting with robotic assistants for industrial and in-home purposes. Zhao et al. [Zhao et al. 2009] utilized AR markers to control house-keeping robots. More recently, Sefidgar et al. [Sefidgar et al. 2017] developed a set of physical blocks with visual markers for robot programming in a pick-and-place task context. Their studies proved the high intuitiveness and learnability of situated tangible programming for robotic assistants. Thus, the similar interaction techniques was adopted in DupRobo. For creative design process, Smithwick et al. [Smithwick et al. 2017] envisioned an intelligent robotic platform that assists architects in tangible prototype design. DupRobo was directly motivated by this vision, and stepped further with tangible control interface for the robot.

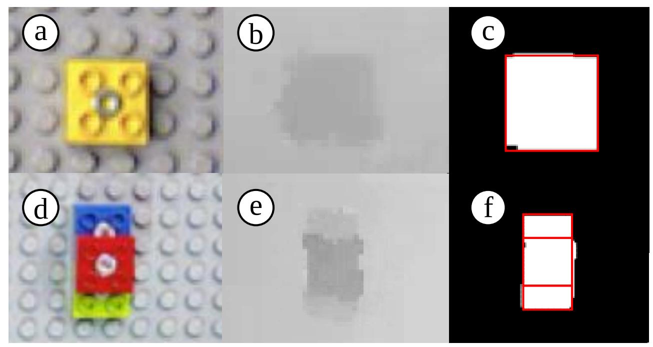

Figure 4: *Block tracking on the construction platform: (a) RGB image of the first block (b) Depth image of the first block (c) binary image of the first block after retangle detection (d) - (f) Tracking of a completed exemplar.*

3 System Description

In the current DupRobo prototype, we used a grey DUPLO board with 32 x 16 studs as the construction platform, and the non-grey DUPLO blocks as the construction pieces. Each DUPLO block was attached with a 1mm-thick iron plate on its surface, for the "grabbing" action of the electromagnet in the robotic arm. There are three main technical components in DupRobo: 3D tracking of the physical exemplar , the paper-based repetition commands, and the robotic arm for the physical autocompletion.

3.1 Physical Exemplar Tracking

Since only 2 x 2 non-grey square DUPLO blocks are used, the computer-vision component performs the process of rectangle and color detection when the user places the blocks on the construction platform. Firstly, the RGB image (Fig. 4 (a))captured by the Kinect sensor is cropped to the region of the construction platform. The cropped image is then converted to the HSV space, and thresholded to eliminate the grey color. Next, image dilation and erosion are performed to obtain the binary image which will then go through the contour-detection process. Finally, the edge filter, the angle fil-

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ter, and the area filter are set to obtain the proper rectangle of a newly placed block (Fig. 4(c)). The on-screen position of the block is then used to update the virtual construction platform by adding a new virtual block accordingly. If there has already been blocks overlapped with a particular location, the new block will be stacked on top of the existing block. Additionally, the Kinect depth image is used along with the RGB image to detect the newly placed block when it is placed on an existing block with the same color.

3.2 Paper-based Repetition Commands

Once the user finishes building the physical exemplar, he/she can then indicate the repetition patterns placing the paper-based commands on the construction platform. We designed seven paper-based markers (Fig. 5) as the repetition commands. The START (Fig. 5(a)) and the END markers (Fig. 5(b)) represent the starting position and the ending position that will be connected by repeating the exemplar. When there are more than two pairs of START and END markers on the platform, the repetition of the exemplar can form a closed shape which can be filled with the exemplar using the Fill marker (Fig. 5(c)). The "Upper Arrow" marker (Fig. 5(d)) indicates the upward repetition perpendicular to the construction platform. Placed along with the upward marker, Fig. 5(e) and (f) indicates repeat two and three times of the exemplar upward. When the user finishes planning the repetition with the markers, he/she places the Go marker (Fig. 5(g)) on the platform. Detecting the Go marker, the DupRobo backend algorithm will generate a virtual 3D preview of the repetition model as shown in the "Repetitive Pattern Generation" box in Fig. 2, and control the robotic arm to construct the model piece-by-piece layer-by-layer.

3.3 Robotic Arm for Model Construction

The 6-DOF robotic arm consists of five off-the-shelf servo motors (Model No.: KS-3518) and one 12V electromagnet as the end effector. When grabbing the DUPLO blocks, the electromagnet will be turned on by the transistor-controlled switch circuit. The five servo motors were controlled by two Arduino boards with motor shields, and the angle of each motor was calculated in real-time using the position of the current to-built piece based on the inverse kinetics.

4 Social Impact and Future Vision

While DupRobo is inspired by Smithwick et al.'s vision of robotic design assistant, we further envision that the robotic assistant in tangible creative process could duplicate the designer's initial design, and perform iterations of the initial design, enabling rapid prototyping of different design configuration. In addition, the robotic assistant can experiment and construct complex possibilities that are difficult for manual efforts , and further provide new design suggestions to the designer. As the future work, we will incorporate multiple robotic arms to construct more complex models.

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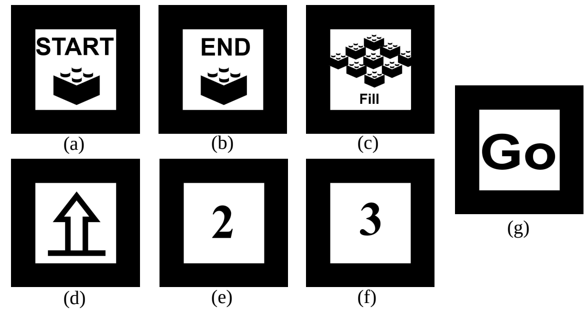

Figure 5: *Maker patterns for paper-based repetition commands*

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