Capacitive Blocks: A Block System that Connects the Physical with the Virtual using Changes of Capacitance

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ABSTRACT
We propose a block-stacking system based on capacitance. The system, called Capacitive Blocks, allows users to build 3D models in a virtual space by stacking physical blocks. The construction of the block-stacking system is simple, and fundamental components including physical blocks can be made with a 3D printer. The block is a capacitor that consists of two layers made of conductive plastic filament and between them a layer made of non-conductive plastic filament. In this paper, we present a prototype of this block-stacking system and the mechanism that detects the height of blocks (i.e., the number of stacked blocks) by measuring the capacitance of the stacked blocks, which changes in accordance with the number of stacked blocks.

Author Keywords
Capacitive block; tangible; building block; stacking; 3D printing; computational crafts; interactive devices

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation (e.g. HCI): User Interfaces.

INTRODUCTION
Many people enjoy playing with toys, such as building blocks and fusible beads, that are made by combining parts using their hands. Motivated by and based on such toys, we developed a block-shaped capacitor that can be printed with a 3D printer. We also developed a block-stacking system, which we call Capacitive Blocks. It allows users to build 3D models in a virtual space by stacking physical blocks, where the system counts the stacked physical blocks by measuring the capacitance and renders them as 3D models in a virtual space. There have been a number of researches on interfaces based on block stacking. Most of those blocks contain electronic devices in the block or need external cameras to recognize how many blocks are stacked. In contrast, our block-stacking system can detect the number of stacked blocks without embedding electronic devices in the blocks and without using external cameras, making the construction of the block-stacking system simple.

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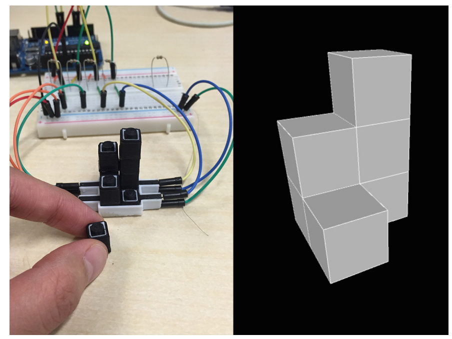

Figure 1: Overview of Capacitive Block system. (Left) Prototype of Capacitive Blocks system. (Right) An application using left mechanism.

RELATED WORK
There are many researches that provide interfaces based on detecting the height of blocks. Chan et al. [4] developed blocks whose surface and contact area were connected electrically. Ando et al. [1] developed blocks that could detect the three-dimensional shape using infrared LEDs and phototransistors spread all over the blocks surfaces. Baudisch et al. [3] developed blocks whose heights were detected using an under-the-desk camera with a fiberglass bundle and a marker in a block. However, these block systems need embedded electronic devices or external cameras, making the system's construction more complicated.

CAPACITIVE BLOCKS
We designed a 7.8×7.8×11.4 mm block whose shape is based on a 1×1 LEGO brick. The block consists of three parts (Figures 2a-2c): two layers (the block's outside and core) made of conductive plastic filament (Proto-Plant Inc.) and between them a layer made of non-conductive plastic filament (Figure 2b). When a user stacks some blocks on a connector of a connection system (Figure 3), the system recognizes the number of blocks on the connector and renders the blocks as 3D models in a virtual space. Recognizing the number of blocks on a connector is based on measurement of the block's capacitance. We used Arduino UNO and Processing 2.0 to measure the capacitance, recognize the number of blocks, and render the 3D models.

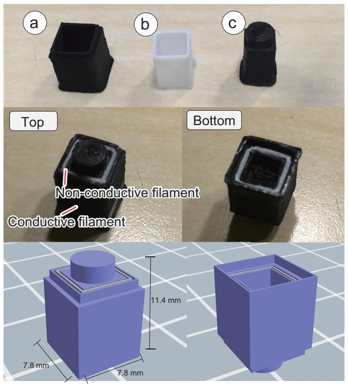

Figure 2: Block of Capacitive Blocks system.

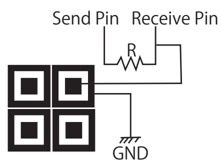

Figure 3: Connection system consisting of 2×2 connectors and its circuit diagram.

Changes in stacked capacitance
To recognize the number of blocks, changes in capacitance are used. Fundamentally, a capacitor has at least two conductors that can store electrical charges by using the electrical potential difference between the conductors. Also, we know that the capacitance of n equivalent capacitors C connected in parallel is nC. Using these fundamentals, we designed and printed the blocks shown in Figure 2 using a 3D printer. A block was found to have a capacitance of 5 pF - 15 pF (mostly around 10 pF). Also, we connected the circuit for measuring the capacitance [2] under each connector. Our current implementation uses a 1 MΩ resistor as R in Figure 3.

Measurement of capacitance
To test how our approach described in the previous section works, we placed 0–5 blocks on a connector and measured the capacitance of blocks including the connection with an LCR meter (DER EE Electrical Instrument, DE-5000). We did this 10 times (i.e., 10 trials) for each number of blocks. We show all the results in Table 1 and the average capacitance with its standard error in Figure 4.

As Figure 4 shows, because the standard error becomes large when the number of blocks is equal to or greater than three,

Times of trials	Number of blocks: 0	1	2	3	4	5
1	4.1	6.75	7.13	7.51	10.69	8.89
2	4.09	10.72	17.24	21.46	21.95	22.41
3	4.15	8.57	10.28	12.22	11.58	10.42
4	4.08	8.67	8.80	9.16	9.34	8.44
5	4.14	10.43	15.84	20.43	20.69	20.57
6	4.1	7.67	10.66	8.27	8.88	9.69
7	4.15	9.63	11.27	12.33	12.96	11.57
8	4.18	9.27	11.65	15.09	15.73	8.66
9	4.1	10.31	14.38	7.69	7.81	8.26
10	4.19	7.58	8.70	7.33	8.61	5.72

Table 1: Measurement of capacitance.

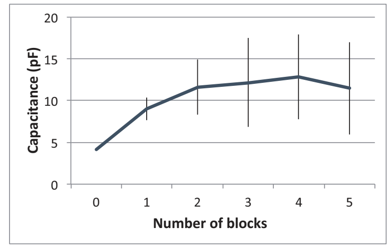

Figure 4: Capacitance averages with standard error bars.

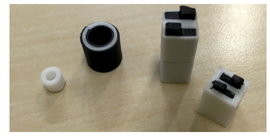

Figure 5: Other shapes of Capacitive Blocks.

recognizing the number of blocks is error-prone. We consider that these results are due to individual differences in the capacitance of the blocks and looseness in the connections of the blocks. To solve these problems, it is necessary to redesign the block so that it has a precise capacitance and a good connection with other blocks.

Other Shapes
Two conductors placed in parallel form a capacitor; therefore, we believe our system can use or even recognize various kinds of blocks (e.g., by using different capacitances as IDs), so we are currently exploring other shapes of Capacitive Blocks such as beads as shown in Figure 5.

CONCLUSION AND FUTURE WORK
We presented a block-stacking system called Capacitive Blocks, which allows users to build 3D models in a virtual space by stacking physical blocks. We also presented the system that detects the height of blocks (i.e., the number of blocks) by measuring the capacitance, which changes in accordance with the number of stacked blocks. In future, we plan to redesign the block so that it has a precise capacitance and a good connection with other blocks to improve the accuracy in recognizing the number of stacked blocks. In addition, as future challenges, we plan to study other block shapes and implement a large-scale connection system, e.g., 8×8 (our current connection system is 2×2), and evaluate the system.

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