Sensor-Integrated Geometric Blocks:

Towards Interactive Play-Based Assessment of Young Children

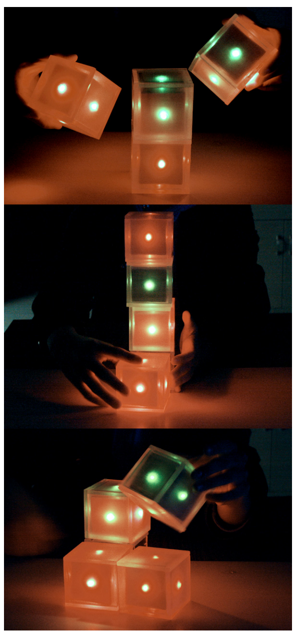

figure 1. Conceptual design of SIG-Blocks consisting of four interactive cubes

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Abstract

In this paper, we present a conceptual framework and a physical prototype of sensor-integrated geometric blocks (SIG-Blocks) for automated play-based assessment of cognitive and fine-motor skills. SIG-Blocks enable remote and real-time monitoring of a person's behavior and performance during play through integrated sensors and wireless communication established between the blocks and a host computer. This paper first describes the conceptual and design framework and then presents the prototype of SIG-Blocks with an interactive graphical user interface (GUI). In addition, to provide a computational method for analyzing complexity associated with play, a quantitative measure of play complexity given a set of geometric blocks is presented based on an information-theoretic approach.

Keywords

Play-based assessment, remote monitoring, geometric blocks, tangible interface, child development

ACM Classification Keywords

H.5.2 Information interfaces and presentation: User Interfaces

General Terms

Design, Experimentation, Theory

Introduction

Children make significant progress in cognitive, social, and emotional capabilities as they grow physically. These early years of a person's life are crucial for learning how to perceive and interact with his or her external environment [1]. During the infancy and preschool periods, children play with various types of toys that stimulate intellectual and physical development. Among such toys, geometric blocks are widely used by children across broad age groups. These toys, unlike other toys or games, are well defined for observing manipulation patterns and developmental transformations during play. They are also well suited for enhancing and learning fundamental mathematics, physics, and general problem solving skills. For these reasons, geometric blocks are often employed in education and clinical practice as a play-based tool for assessing cognitive and learning capability [2]. In addition, experiments using simple geometric blocks demonstrated infants' consistent understanding of how to rotate objects to make them fit into an aperture beginning at the age of two [3]. Enabling up-to-date technology, Mitsubishi Electric Research Laboratories developed self-described building blocks (MERL's blocks), which detect how they are connected to their immediate neighbors to describe the assembled configuration [4]. AlgoBlock with a tangible programming language and Cognitive Cubes are also examples of technology-enhanced geometric blocks with computer-human interfaces [5, 6].

In this paper, we present a conceptual framework and a physical prototype of sensor-integrated geometric blocks (SIG-Blocks) that provide a novel procedural and methodological tool for automated play-based assessment of children's cognitive and intellectual skills. Furthermore, they are fully individual homogeneous modules without a specific master block, and each block communicates with a computer independently and wirelessly. This paper also presents an information-theoretic method to analyze the complexity associated with play, given a set of geometric blocks. This method is then applied to the design of a physical prototype.

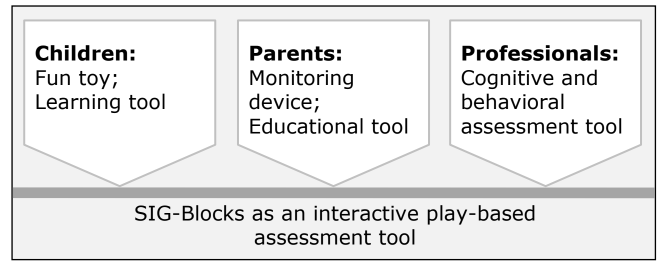

figure 2. Conceptual overview: SIG-Blocks target three groups of end-users, children, parents and professionals.

Conceptual and Design Framework

Despite the great potential for wide applications and a large number of existing end-users, commercially available geometric toys are not comprehensively designed for research purposes. Without any built-in feedback mechanism in these toys, an external device and/or a person is needed to monitor the child's behaviors during the entire play. SIG-Blocks provide real-time feedback and monitoring capabilities by integrating state-of-the-art technology, including sensors and wireless communication. This new generation of toys will be fun games for children, a self-assessment and educational tool for parents or teachers, and an advanced research or diagnostic device for related professionals (figure 2).

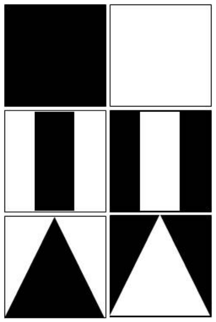

figure 3. Images of re-attachable cover cards with 4-, 2-, or 1-fold symmetry

In the assessment using SIG-Blocks, a child will be given a set of SIG-Blocks and a series of goal assembly configurations to accomplish by manipulating the blocks. Target information to be acquired during play include the following: ***a***. overall activities; ***b***. step-by-step completion times; ***c***. assembly or manipulation patterns; and ***d***. performance changes through repeated play and/or varying levels of support provided to a child. Hand manipulations required to play with geometric blocks are broadly categorized into insertion, reconfiguration, and assembly. The SIG-Blocks presented in this paper is designed for assembly tasks.

Play Complexity: In order for SIG-Blocks to be implemented as an assessment tool, they should be neither too difficult nor too easy to effectively capture individual differences. To provide additional computational data for analysis, we define *play complexity* associated with geometric blocks based on information-theoretic entropy. Entropy is a statistical tool for quantifying the amount of uncertainty or information associated with an event that involves a random variable(s). We first assume that each set of geometric blocks is intended for a specific type of play (e.g., insertion, reconfiguration or assembly) and the final objective is well defined. Then, the *play complexity* is defined based on the entropy changes in geometric blocks during play:

$$\mathbf{C}^{play} = \mathbf{H}^{initial} - \mathbf{H}^{final}$$

where $\mathbf{H}^{initial}$ is the entropy for a given set of geometric blocks before play and $\mathbf{H}^{final}$ is the entropy computed for the blocks after a child accomplishes the goal. In other words, $\mathbf{H}^{initial}$ implies the amount of uncertainty initially existing in the blocks and $\mathbf{H}^{final}$ is the amount of uncertainty remaining after play. Thus, the difference between the two indicates the amount of uncertainty reduced, or information handled, by a child manipulating the blocks to achieve the goal configuration. The play complexity can be used to design SIG-Blocks with varying levels of difficulty in terms of the amount of information required to complete the task. We note that a higher value of $\mathbf{C}^{play}$ implies a more difficult level of play.

Prototype

Hardware: SIG-Blocks consist of four homogeneous modules. Each block contains a microprocessor, a wireless communication module, and several sensors including a tri-axial accelerometer and six optical sensors. An accelerometer provides rotational information for each block, and six reflective optical sensors detect the assembly configuration of the blocks. Each SIG-Block has a unique ID that enables communication with the host computer independently. The blocks presented in this paper are identical to each other; however, replacing the outer covers with different shapes or figures can easily change the outer design of each block. Therefore, SIG-Blocks can be used for various types of experiments with varying play complexity while significantly reducing the manufacturing time and cost. Each block is self-powered with four 1.2 Volts rechargeable batteries where the running time is between 4 to 5 hours. The data collected by the host computer can be read in real time via wireless communication. 3D graphic models of SIG-Blocks are displayed and shown along with collected sensor data in a GUI designed using OpenGL and C#.

Re-attachable cover images used in the physical prototype are shown figure 3. These six images are placed in the surfaces of each block. Using the play

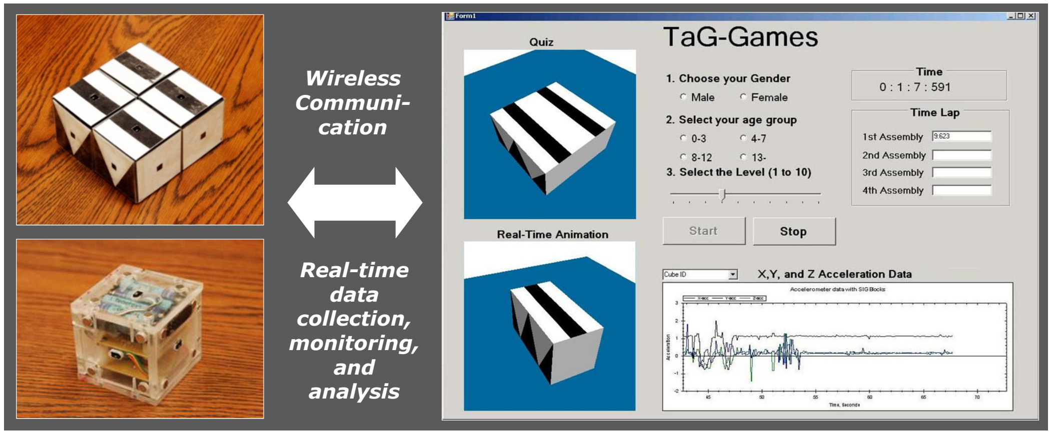

figure 4. SIG-Blocks and the interactive GUI: The layout and display components of the GUI can be easily customized depending on each use.

complexity defined in this paper, $\mathbf{C}^{play}$ for our prototype can be calculated based on the number of possible orientations and assembly configurations, such that $\mathbf{H}=\log_2 W$, where W is the number of all distinctive configurations [7]. Depending on the goal assembly configuration (shown as "Quiz" in figure 4), $\mathbf{C}^{play}$ can vary from 10.34 to 22.92.

User Interface: The GUI provides a 3D animation of the blocks and sensor data (orientation and assembly detection) in real time. The collected data is stored in a host computer and can be easily retrieved at any time for further data analysis. Figure 4 shows our initial user interface displayed on a computer screen. The game interface animates the 3D models on the left side of the screen and shows the real-time rotational movements and assembly configurations of SIG-Blocks; time for each assembly is recorded on the right side. The graph at the bottom shows tri-axial acceleration data simultaneously. The game level can be selected by a player or an assessor.

Discussion and Future Work

We presented a conceptual framework and a physical prototype of SIG-Blocks as a means for a new automated and procedural method for play-based assessment. The developed system has been tested in a laboratory setting to verify technical feasibility. In order for the proposed technology to be used beyond the level of currently available assessment tools, extensive and large-scale experiments would be necessary.

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