Abstract
For this project, we will describe a tangible media toy intended for infants that affords squeezing and shaking. SmartBall is a deformable soft ball with embedded electronics that can sense infants’ behaviors and can interact. Its functions include; (1) ability to sense its deformation after being squeezed, (2) ability to sense coordinate orientation from shaken, (3) ability to generate different musical tones based on different grip positions, and (4) ability to generate tactile vibration when shaken. Measured data is transmitted through wireless communication and is analyzed by an accompanying graphical user interface. The target age is from the birth to 2 years of age because this age group cannot easily communicate verbally, but SmartBall is designed to be interesting to all age groups. This paper covers our motivations for creating the SmartBall, technical specifications of the prototypes, and our plans for its usage and further development.

Keywords
Geometric Toys, Affordance, Creative Play, Behavior Analysis

ACM Classification Keywords
H5.2 Information interfaces and presentation: User interfaces - Prototyping
Introduction and Motivation

An affordance of an object is its ability to allow a person to perform certain actions on it. It was first addressed by Gibson [1] and introduced by Norman and Gaver to the field of Human-Computer Interactions (HCI) [2, 3]. The concept has been interpreted differently in order to address issues related to the usability of designed systems. According to Gibson [1], an affordance is defined as the possibility of an action. More generally, it can be seen as the opportunity that an object offers for a person to perceive, act, and interact with that object.

Babies love to grasp, squeeze, suck, and move objects [4]. They are also aware of and respond to sensory stimuli provided from the environment [5]. For infants, affordances are even more important because they do not have fully developed verbal skills and also start their cognitive, physical and emotional development through interactions with the environment [6]. This can be viewed as that affordances are a way for babies to communicate with or express themselves to the world where they belong.

Studies have shown that the fundamental affordances for infants include grasping, squeezing, and sucking, as well as, sensory awareness and responsivenes such as tracking moving object and response to sound and light [7]. In general, at around four months of age, an infant smiles and can recognize his or her name [8]. About one year of age, babies can say their first words [6]. Verbal communication takes place as they learn vocabulary from this stage, but nonverbal communication skills are established long before they speak their first word. For example, they can express that “I am hungry” or “I am lonely” by crying. Babies also use gestures to express their opinions such as like or dislike.

This paper presents our ongoing work developing an interactive toy for young children by combining these behavioral observations with the concept of affordance. A sensor-embedded toy ball with sensory feedback, called SmartBall, is designed to enable and stimulate babies to communicate with the physical world, learn cause-and-effect relationships, and develop small-muscle coordination skills through interactive play. The embedded sensory feedback, such as melodies or vibrations generated by squeezing the ball in different locations, will help stimulate children’s cognitive development. The target age group is from 0 to 24-month olds who have not been fully developed verbally and mostly rely on gestures or other nonverbal skills as a means for communication [9]. However, anyone regardless of age can play with SmartBall.

Design Concepts

SmartBall is designed to provide a fun experience for infants to explore physical objects with sensory feedback through tangible interactions and creative play. More importantly, our goal is to develop SmartBall as a play-based assessment tool for infant’s behavior in the hope of catching insightful information about a child’s developmental status early on. The ball shape was selected over many other shapes for safety since it does not have hard edges and for simplicity since it is easy to grab or handle. Auditory and tactile stimuli were considered for providing sensory feedback to the baby while playing. Additional visual stimuli can also be added, for example, by embedding LEDs on the surface. Fig. 1 shows the conceptual framework of SmartBall.
Figure 1. Conceptual Framework: SmartBall is a novel playful toy equipped with sensors and auditory and tactile feedback modules engaging babies to play with it by touching, squeezing, shaking, or throwing.

The overarching design criterion for this toy is safety because it is intended to be played by young children. The detailed safety considerations are listed below:

- SmartBall is covered with a non-toxic material without paint that is detachable and washable.
- It does not have any sharp edges/points, rough surfaces, or broken/loose parts.
- It contains no (or minimal) risk caused by embedded electronic components, such as electric shock by leakage.
- It does not generate excessively loud tones or strong vibrations.
- Its size is balanced between being light enough to grasp and hold easily, and being large enough that there is no risk of swallowing.
- It is covered with a soft material for safety and also for babies to hold and squeeze it easily.

Technology Description
The developed prototype consists of hardware with embedded sensors and associated software with a graphical user interface (GUI).

Hardware: SmartBall
SmartBall is composed of three parts: a core module, a deformable sponge layer, and a washable outer cover. The core module contains a tri-axial accelerometer (MMA7260), a ZigBee-based wireless module (XBee), a piezoelectric buzzer, a vibration motor, a 3V rechargeable lithium coin-cell battery, and a microprocessor (Atmega 328). The wireless module (XBee) consumes a large portion of power, and therefore its usage is optional. Wireless communication allows real-time behavioral assessment and monitoring while a baby plays with the ball. Alternatively, the sensor data may be stored in an on-board memory card and retrieved later for review.

To detect where and how the ball is grasped and manipulated, two different design structures were considered: spring-loaded push-button type and elastic latex film type as shown in Fig. 2. In order to simplify the prototyping process and reduce the cost, the elastic film was selected over the push-button type. For sufficient elastic behavior with electric isolation, we used a latex film. When the latex film is pressed, a copper film touches two separated pads at the bottom surface so that the digital input pin is set high as shown in Fig. 3. The core module is then covered with sponge sheets. The sponge sheet was cut vertically and tied at the top and the bottom as shown in Fig. 4 in order to make a sphere shape while securely covering the core module. These simple push-button contacts detect where and how strong the baby grasps the ball.
also work in parallel with a tri-axial accelerometer, which estimates the ball’s orientation and detects applied motions.

Figure 2. Two candidates for the inner design: spring-loaded push buttons (Left) and elastic film-based touch surfaces (Right).

Fig. 5 shows the internal view of SmartBall with embedded electronics. Two half shells are assembled and 12 touch faces are connected to 12 digital I/O pin and 2 digital I/O pins are used for generating melody and vibration. 1024 bytes of EEPROM can save up to about 200 notes. Figure 6 shows the steps for assembling a SmartBall. The step-by-step assembly procedure is shown in Fig. 6. Fig. 6(a) shows half shell covers with embedded electronics inside. Fig. 6(b) shows a fully assembled core module. It is then covered with a sponge layer (c), and finally, a washable fabric cover is put over the sponge layer (d).

Figure 3. Details of grasping sensing mechanism

Figure 4. Steps for making sphere shape sponge hollowed inside: cut several strips vertically and tie the top and bottom

Figure 5. Schematics of SmartBall and embedded electronic components.

Figure 6. Internal and external views of the prototype of SmartBall.

SmartBall can generate 12 tones, C, C#/Db, D, D#/Eb, E, F, F#/Gb, G, G#/Ab, A, A#/Bb, and B, when pushed in 12 different locations on its surface. This covers a full
12-tone chromatic scale that can be used to generate a wide variety of simple melodies or songs. Creating melodies through gestures such as stretching or squeezing can increase the perception of control in collaborative musical environments [11]. In addition, the elastic sponge cover and a vibration motor provide tactile feedback. We believe that such feedback mechanism will provide sensory stimulation to babies.

Additional technical specifications of SmartBall are listed below:

- Size: 5.0 cm in diameter when it is squeezed, 7.0 cm in diameter when released.
- Weight: 45g when fully assembled.
- Power: Approximately 2 or 5 hours of running time with and without wire communication, respectively. SmartBall will switch to a sleep mode when no action is sensed in order to save power consumption.
- Processor: Atmel ATmega328, 14 digital input/output pins, and 8 analog input pins. 1024 bytes of EEPROM.

**Graphical User Interface**

To visualize the data collected from SmartBall, we developed a GUI using visual C# as shown in Fig. 7. Tri-axial accelerations and melodies generated by the player are displayed. This is primarily intended for parents or professionals in order to enable child’s behavior and performance observation over time. The layout and display elements of the GUI can be easily customized.

**Discussion and Future Works**

This paper presented the conceptual framework and a physical prototype of an interactive baby toy, SmartBall. SmartBall is designed as a fun toy for young children that can physically demonstrate cause-and-effect relationships through embedded sensory feedback while stimulating fine motor skills. It can also measure behavioral characteristics, such as grasping patterns, forces applied to the ball, and hyperactive or repetitive motions, which may provide an important insight about a child’s cognitive, physical, and emotional development. Auditory and tactile feedbacks, such as melody tones and vibrations, are likely to attract children’s attention without any foreseeable harm. We will test SmartBall on adult participants for
preliminary safety and usability, and then conduct another study involving infants for evaluating the proposed technology in terms of its entertaining features as well as behavioral assessment. This technology will enable a wide range of game ideas for young children. Multiple SmartBalls with different colors and sizes can be employed for various games and experiments.

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References