Designing Toys with Automatic Play Characterization for Supporting the Assessment of a Child's Development

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Abstract
In this paper, we describe the design considerations and implementation of the Child'sPlay system, a technology for supporting the automatic recording, recognition, and quantification of a child's object play behaviors for retrospective analysis. Our prototype system consists of six varieties of toys augmented with wireless sensing capabilities and a mobile computing platform which uses statistical pattern recognition techniques to automatically classify sensed play behaviors. This paper discusses our choices in toy design both in form factor as well as sensing capabilities. In addition, we also describe the play activities the system supports and provide an overview of our initial recognition algorithms.

Keywords
Activity Recognition, Toy Design, Object-Play, Multimodal Wireless Sensing

ACM Classification Keywords
H3.1. Content Analysis and Indexing;

Figure 1: Child'sPlay components consist of sensor augmented toys and a mobile computing platform to receive data

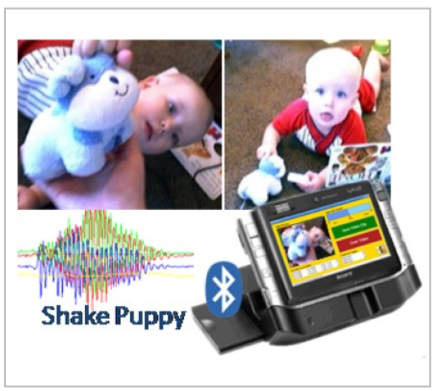

Figure 2: The Child'sPlay system collects rich data from an infant shaking a toy and uses statistical methods to annotate the data for late review.

Introduction & Background Motivation

The early identification of children with developmental delays is an important public health goal [5]. However, the wide variation of typical development among children can make establishing the presence of a developmental delay a difficult task. Subtle abnormalities can often be overlooked as normal developmental variation [3]. Therefore, the routine monitoring of a child's progress is crucial to the identification of delays and is considered a vital component of pediatric care [9].

The Center for Disease Control lists over 200 milestones to track over the first five years of a child's life [4]. Developmental skills can range anywhere from banging a toy on a table to displaying socially appropriate expressions. Specialists often use a subset of these milestones in screening diagnostics, and recent research in psychology suggests that the observation of object play interactions may help identify early indicators of certain developmental delays [1],[2]. Psychologists have created a coding scheme which quantifies the levels of sophistication displayed by infants while engaged in object play. Baranek *et al.* used this scheme to identify the highest level of sophistication reached per child and found that the duration of play at each level differed between typically developing children and children with autism [2].

Recent formative research suggests that parents may benefit from increased technological support in tracking their child's developmental progress [6]. Children's play activities often center around playing with toys. As such, we can leverage toys to assist in the automatic capture and annotation of developmental data. One goal of Child'sPlay is to help increase the awareness and understanding of a child's development by automatically providing quantitative measures of toddler-object interactions, annotations of data, and a way to view rich forms of this play data. To support this analysis, Child'sPlay uses statistical pattern recognition techniques and wireless sensors embedded in specially developed toys to identify play activities associated with developmental milestones (see Figure 1 and 2).

This paper discusses the motivations behind the selection of the activities supported by Child'sPlay followed by a discussion of the sensing challenges and requirements that must be met by the toys. We end the paper with a discussion on our initial pilot study and the implications for the Child'sPlay system.

Play Behaviors to Recognize

Child'sPlay will support a subset of play activities, similar to those studied in clinical research. In particular, the system will automatically generate quantitative data from observations of children engaged in object play similar to that produced by the coding scheme of Baranek *et al.*. These measures include the frequency with which an object is played, the time spent attending between different objects, and the highest level of play sophistication reached by a child. Based on Baranek *et al.*'s work, our technology will focus on recognizing toy manipulations such as grasping, rubbing, shaking, rolling a car, pushing a button, pushing apart Lego-like blocks, removing lids from containers, pouring, stacking, blocks, and early imaginary actions (see Figure 3). To detect the play activities described by Baranek, we used the adapted approach of Minnen *et al*. [7] that classifies activities based on aggregate features computed over a short temporal sliding window.

Toys \ Behavior	Grasp	Rub	Shake	Bang	Mouth	Roll	Pull Apart	Stack	Scoop	Pour	Cover	Join
Puppy	✓	✓	✓	✓	✓							
Caterpillar	✓	✓	✓	✓	✓	✓	✓					✓
Ring	✓		✓	✓		✓		✓				
Lego	✓		✓	✓			✓	✓		✓		✓
Lego w/ wheels	✓		✓	✓		✓	✓	✓				✓
Lid	✓		✓	✓		✓			✓		✓	
Dome	✓		✓	✓		✓	✓	✓	✓	✓		✓

Figure 3: The Child'sPlay augmented toys and the activities they promote. Activities are based on the first five early levels of object play (colored columns) described by Baranek *et al.*.

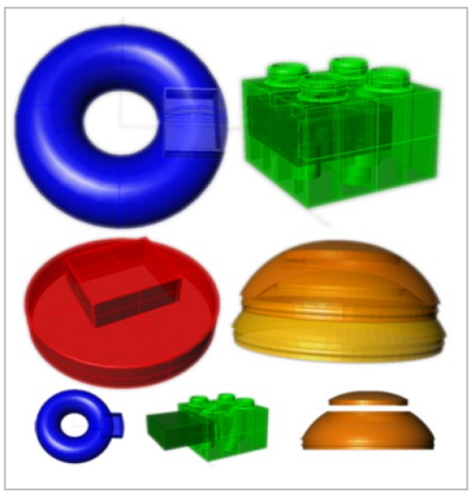

Figure 4: Models of our augmented plastic toys revealing where and how the sensor is inserted into the toys.

Sensing Considerations

Several trade-offs exist in the development of a play sensing system, including sensor type, power consumed, and form factor. The types of sensors used and form factor of the toys influence the quality of data we can record. Regarding the design requirements of the form factor, the sensor should be easy to charge, have maximum protection from daily use, be unobtrusive, and remain in position during use. Embedding the sensor within the toy addresses many of these issues and maintains the original safety properties of the toys. It can also help keep the sensor in the proper position to allow for consistent data recording and can prevent the sensor from becoming exposed to the child while in use. The form factor also determines the ease with which the sensors can be accessed by caregivers to remove for toy cleaning maintenance and for charging the battery. However, finding a balance between ease of access for adults and preventing the children from accessing the sensors can be difficult. Designs that require manual dexterity, such as screw tops and/or constant force are often good for preventing children from accessing the hardware.

While no one sensor is ideal for automatic play recognition, a fusion of sensors can help increase the range of activities that can be detected. Our toy designs favor the multiple modality BlueSense integrated wireless sensor package [8]. The BlueSense sensors detect motion, sound, and touch via 2 audio analog inputs, 2 capacitive touch-sensing inputs, and an on-board 3-axis accelerometer. They measure about 1.8x1.8 inches (4.6 cm) and can transmit data continuously for about 10 to 12 hours using a light rechargeable 3.6V 750mA battery.

The sensing modalities supported by BlueSense are well suited to the range of play activities that we are trying to detect. However, there are two main disadvantages to using an integrated approach. First, because we are using a smaller, lighter battery, it will require more frequent charging. Second, using a centrally embedded sensor package means that some of the integrated sensors will not have optimal positioning. For example, the microphone will not have external exposure, but rather be inside the toy. One of our designs will explore using conductive threads and fabrics to address this issue for sensing touch.

Toy Selection and Form Factors

We have designed and implemented six toys to collect data about infant object play behaviors. These toys include a plush puppy rattle, a plush caterpillar, plastic Lego Quatro™ compatible blocks, a plastic stacking ring toy, an abstract shape resembling a cooking pot lid, and plastic stacking domes (see Figure 4 and 5). All of the toys are designed to use the BlueSense sensing unit enclosed in a friction-fit plastic case that is embedded within the toy. The plush toys contain social faces to encourage engagement with the toys. The ring, lid, and dome toys are rounded objects based on a similar circumference to encourage stacking, covering, and scooping activities. An important specification of our design shared by all toys was safety. All toys are large enough so children cannot swallow them. All of the toys except for the plush caterpillar and the cooking pot lid are modeled from existing toys approved for infant use. Each toy continuously transmits data via the Bluetooth sensor to a mobile computing device where it records and processes the data.

Figure 5: Commercial Toys with augmented counterparts in white. The sensor units exposed to show how they are embedded

Table 1: Activities observed during pilot play tests with both adults and children

Play Components			
move	spin	bang	relate
pickup	spinning	bump	release
pour	stack	drop	reverb
push	takeout	separate	roll
putdown	unstack	manipulate	rub
join	shake	knockdown	grasp

Pilot Study and Discussion

We have conducted initial play tests with five adults and three children over a minimum of two 20 minute sessions per participant. These sessions allowed us to test the durability, appeal to children, and data transmission capability of the toys as well as the ability of our algorithm to properly detect relevant play activities. Our initial exploration of the play data has revealed 25 distinct classes that comprise the basic play actions Child'sPlay will recognize. These play activities are listed in Table 1.

As a result of our initial work, we learned that our ABS plastic and conductive textile toys were durable, functional as toys, of interest to children, and concealed the sensor from the participants. Our toys withstood throw, drops, and kicks that occurred during play. However, our play tests did expose an important challenge with constructing the automatic recognition portion of Child'sPlay. The most prominent challenge will be collecting enough training examples to build models for recognition. While we can script play scenarios to help encourage children to engage in the types of play we are trying to detect, there is no guarantee that the child will be willing to comply. This problem is further complicated by the fact that our target age group is children ages 10-24 months old. Some of these children may not have yet formed language, nor will they be receptive to instructions by adults. Thus, we cannot instruct them to play with the toys in a way that will elicit proper training data. Our current solution bootstraps the models with adult data.

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