bioToys: Playful Rehabilitation Tool for Encouraging Children Self-initiative Training

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ABSTRACT
In this paper we introduce bioToys, playful rehabilitation tools for encouraging children self-initiated training in children. Our objective is to provide a novel rehabilitation experience with playful and social interaction for children with special needs, in particular for those with congenital defects of the upper limbs. We surveyed physical therapists and families of these children to understand the problems these children had in learning to use electronic prostheses. We observed that children get bored of therapeutic activity and that adequate understanding of the prosthesis and participation of parents, as well as of the requirements of social interaction during physical therapy, were all vital to therapeutic assessment. Based on these considerations, we defined bioToys requirements to realize playful rehabilitation tools. We have been developing a building block type bioToys. In this study, we demonstrated that this system allows the user to use and handle the developed blocks in the same way as normal building blocks.

Categories and Subject Descriptors
H.5.3 [**Group and Organization Interfaces**]: Collaborative computing; J.3 [**Health**]

General Terms
Design

Keywords
Rehabilitation, Toys, Tangible interaction, Playware

1. INTRODUCTION
Children with physical disabilities such as congenital loss of limbs usually use prostheses for daily activities. In most cases, the child's parents want to let their child use the prosthesis. Especially for the upper limbs, prostheses can be classified by their function; cosmetic, body powered and electronic prosthesis[10]. Electronic prostheses make motions such as griping or wrist rotation by sensing the user's motion intention. Recently, some kinds of electronic upper limb prostheses have been developed as well. Yoshikawa et al. developed a rapid personalized prosthesis by using 3D printing[15]. Their upper limb prosthesis operated by using a distance sensor on the body skin. In another approach, electromyographic (EMG) signals are used for motion intention estimation. For assignment of opening and closing functions and their velocity, myoHand (Ottobock Co. Ltd.) measures the EMG signals of two muscles, the extensor and the flexor, and uses them as motion intentions.

Patients with loss of an upper limb can obtain a prosthesis with a doctor's prescription, and they are treated by a physical therapist to habilitate with the prosthesis. In this case, the patients train to adapt to their upper limb prosthesis and learn how to use it through training, assisted by the physical therapist. Since the physical therapist's main goal is to restore the patient's quality of life (QOL), the therapeutic activities consist of repetitive tasks that require the patients to use both hands based on activities of daily living(ADL). For example, the patient ties a string by holding the string with the prosthesis and tying the knot with the healthy limb [10, 5]. In this regard, therapists and prosthetists confirm that by using biofeedback[2] the patient can generate proper EMG signals, when EMG electrodes are set at the proper position on the skin. There are various assessments of upper limb functions such as the Simple Test for Evaluating Hand Function(STEF)[6] and Assessment of Capacity for Myoelectric Control(ACMC)[3].

In case of children with a unilateral congenital defect of the upper limbs, there are several problems regarding the use of prostheses. The first problem arises when the children start to use prosthesis [2, 1]. In case of congenital loss of limbs, if the children have never used an upper limb prosthesis until the age of one and a half years, they would have learned compensatory motions and would find difficulty in adapting to the prosthesis. For example, children with congenital unilateral upper limb loss who learn to crawl without prosthesis will find difficulty of adapting to the prosthesis afterwards, in contrast to children who learned to crawl with prosthesis. If those children learned to crawl without prosthesis, physical therapists will have to make extra efforts in the treatment process.

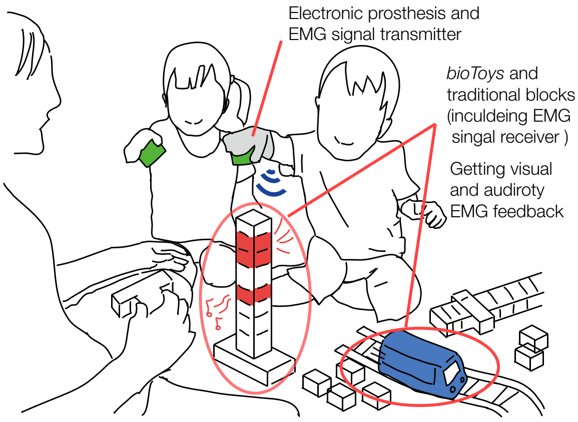

Figure 1: bioToys concept

Second, even if the parents want their child to use a prosthesis, children might reject using it because of ensuing parental depression due to the lack of functionalities of the prosthesis, as reported by Postema et al.[9]. Postema pointed out that for optimum results of prosthetic rehabilitation, it is essential to not only prevent the disappointment about prosthetic benefits but also to provide parents with sufficient involvement in treatment and with adequate guidance.

In addition, training contents based on STEF and ACMC are constructed by simple and repetitive tasks such as gripping, holding and releasing. Some children fail to be attentive and easily lose interest in training because it becomes boring and repetitious. Physical therapists make additional efforts to develop programs that attract a child's attention while training. Matsubara et al. [7], developed a assistive device that is easy to holding a violin bow by a prothesis for playing a violin, and group training session in order to encourage children's self-initiated activity and to promote long-term use of prostheses. They suggest that for children to use the prosthesis it requires the cooperation not only of children with a disability but also of children without disabilities. Finally, focusing on social environment (e.g., in school classroom) reveals that students without disabilities have negative attitudes toward peers with a physical disability. Westervelt et al. [14] intervened between children with disabilities and those children without to solve the misunderstanding. They showed that their intervention could be helpful for promoting a positive attitude from children without disabilities toward those with disabilities.

From these results, we hypothesize that in order that children can adapt and learn to use a myoelectric prosthesis for a long time, children should be encouraged to generate EMG signals and their parents or friends should also join and understand their training. We aim to develop a toy-like modular system that encourages self-initiated rehabilitation activity. The proposed system enables a physical therapist as well as family to see the children's training outcome both in qualitative and quantitative terms and also promotes social activity between children and friends or families. We propose a playful rehabilitation system for children called " bioToys"[12]. The concept (Figure 1) is a creative biofeedback system for playful and self-determined physical therapy that encourages people to promote collaboration and competition with therapists, family, friends, and others.

2. METHODOLOGY

We assume that this concept requires both a physical therapeutic point of view and a playful interaction one. From the physical therapeutic point of view, *bioToys* is required to be *meaningful* and *practical*. From the playful interaction point of view, this system is required to be *accessible*, *flexible* and *collaborative*.

2.1 physical therapeutic activities

Meaningful refers to the user being able to understand the causality which includes a real-time bond and accuracy between biosignals and the system's output. Because biosignal measurement is very sensitive to noise generated by body movements, it is important to process the biosignals in real time to generate appropriate stable output. Examples of meaningfulness include the method of heart-beat pulse detection, estimation and visualization by wearable device[11], the method of real-time sonification of EMG signals to understand the motion dynamics [8], and displaying the shape and brightness of activated muscles directly on the body [4]. *Practical* refers to the physical therapists being able to incorporate the system into rehabilitation programs. According to rehabilitation assessments such as STEF and ACMC, *bioToys* is required to be usable for all hand tasks: gripping, holding, and releasing. In addition, through biosignal measurement and biofeedback, the physical therapist must be able to understand the children's conditions such as EMG signals, level of activity and how long they use the prosthesis.

2.2 playful interaction

The concept of *Social Playware* is to realize playful interaction between several users with interactive tools that integrate intelligent hardware and software [13]. To attract children's attention to train and use the system at the hospital and at home, *bioToys* as a Social Playware must be *accessible*, *flexible* and *collaborative*. From the clinical and home health perspectives, *accessible* means that the device should be easily used by children and physical therapists and their family. In addition, medical conditions differ among children having distinct preferences and interests and possibly changed at each therapeutic phase. Thus, it is important for the system to be *flexible* regarding to the training programs on site, and that not only physical therapists and parents but also children modify them to fit the user requirements. Finally, since therapy sessions are usually attended over several weeks or months to be effective, the children have to be motivated to self-initiate playing and training. To help maintain their motivation in a social environment, collaboration is required. *Collaborative* refers to promoting cooperative tasks between the physical therapist and the families.

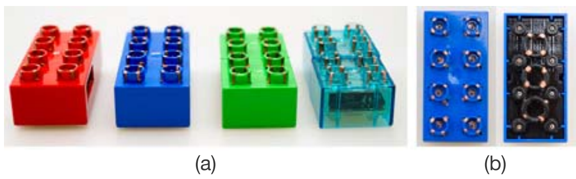

Figure 2: Overview of the developed blocks

Table 1: Example block types

Category	Specific type	Functions
Link Block	Normal	Disconnection between blocks
	Bridge	Connection between blocks
Power Block	Battery	Supply voltage to the blocks and monitoring power line
Processing Block	Signal Processing	AD conversion, processing of sensor signal and transmitting to received block
	Wireless Receiver	Receiving data from sensor and transmitting data to power line
	Parameter Tuner	AD conversion of a volume voltage and transmitting data to power line
Action Block	Motor	Get data form power line and interpret the data then generate output for driving each element
	LEDs	
	Sound	

3. BUILDING BLOCKS SYSTEM

Much of the work on tangible user interfaces focuses on educational benefits, especially as tools for learning science and programming languages. These tangible systems allow multiple users to freely build a system with their own hands, which will produce an outcome under the combination of properly built blocks with particular functions. These processes are *practical*, *accessible*, *flexible* and *collaborative*. We hypothesize that tangible user interfaces such as systems of building blocks are effective physical rehabilitation tools for children to learn about usage of upper limb prosthesis and could also encourage the learning process voluntarily and in a creative manner. We therefore developed a building blocks type of *bioToys*. This system is designed for users to understand the causality between biosignals and system outputs in an intuitive manner, and can encourage children to self-initiate playing and training. In addition, handling the system is easy for the physical therapists, children and their families.

3.1 Device Overview

Figure 2 shows an overview of the developed blocks. Electronic circuits are embedded into the DUPLO ®(LEGO Group) blocks, and four types of blocks are developed: a link block, a power block, a processing block, and an action block (see Table 1). These block-type devices are modified from the original blocks with two connectors designed like a coaxial socket. The device shapes are almost the same as the original blocks and they can be connected to modified blocks and to regular DUPLO blocks as well. Thus, users can handle them without special introduction of this device, and without limitations regarding connection rules. In the proposed system, power is provided to each block from a battery block, which behaves as a master of the system. To realize connectors designed like a coaxial socket, power line communication is used to share information between blocks. Therefore, even if the developed blocks have particular electrical connections and functions, the physical connection between blocks is not constrained. This mechanism allows the user to use and handle the developed blocks in the same way as normal building blocks.

Figure 4: A developed toy train based on the motor action block

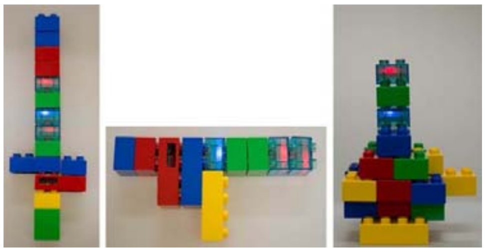

Figure 5: Outcomes of using the proposed system with original blocks: a sword, a gun, and a tower

3.2 System Overview

Data communication is performed over the power line and the network topology is a bus network. When the battery block is switched on, blocks connected to the power line start to work according to their respective functions. Any blocks connected to the network, broadcast data and share the circuit signals by serial communication. Via this network, the battery block monitors power line communication and logs related information: how many blocks are added to the network or what kind of blocks are present. For generating biofeedback, the system has basic three rules: users use at least one power block; connect the power block with processing block, which is a wireless receiver connected with EMG sensors attached at the upper limb prosthesis; and add any action block to complete the network.

4. PLAYFUL PERFORMANCE

To confirm that the proposed system has the properties of being *accessible*, *flexible* and *collaborative*, we demonstrate some cases of using the proposed system. Figure 3 shows a healthy participant using the proposed system and the original blocks. The participant wore a wearable EMG sensor and configured a combination of a battery block, a wireless receiver, and two LED blocks. After building the blocks, as she moved her wrist to generate the extensor EMG signal, the LED blocks illuminated, and their intensity was dependent on the EMG signal. Thus, we confirmed that the user can use the developed blocks together with traditional ones.

In addition, we have developed a toy train system based on the motor action block (see Figure 4) that can move the train both forward and backward. This train system was inspired by antagonism control training of extensor and flexor muscles. For generating proper EMG signals, children with a congenital defect of the upper limb acquire a method for using their muscles separately through physical therapy. The train has two kinds of connectors, placed at the front and

Figure 3: Experimental scenario: Playing by using muscle activity and LED blocks: She moved her wrist to activate the flexor muscle. Then LED orange color blocks were illuminated.

back sides of the roof, assigned to control the forward and backward motion, respectively. A set of wireless receivers and parameter tuning blocks are affixed to the train on different sides of the roof, and the train will move forward or backward according to the built block configuration.

Figure 5 shows some experiments that demonstrate creative outcomes. In this figure, we used a battery block, a wireless block, two bridge blocks, three LED blocks, and some original blocks. Different configurations are built with the same number of *bioToys* blocks, and the user changed the configuration freely and rapidly to modify the system's configurations, creating, e.g., a sword, a gun, and a tower. This experiment demonstrates the flexibility of the proposed system. These examples showed that the proposed system can be realized in a *flexible* manner and also confirmed that the system is *accessible* and *collaborative*, similar to the original DUPLO blocks.

5. CONCLUSIONS

We surveyed the problems of children with a congenital defect of the upper limbs. By considering therapeutic activities for children and their social environments, we defined *bioToys* requirements that are *meaningful*, *practical*, *accessible*, *flexible*, and *collaborative* for realizing creative rehabilitation tools. We have developed a building block system, implementing the functions of *bioToys* on DUPLO blocks. This system allows the user to use and handle the developed blocks in the same way as normal building blocks for maintaining *accessible*, *flexible*, and *collaborative* characteristics. In future study, we will confirm through clinical experiments that the proposed system is both *meaningful* and *practical*, and also contribute toward quantifying the exploratory action during therapeutic activities by these of logs.

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