A Paraeducator Glove for Counting Disabled-Child Behaviors that Incorporates a Bluetooth Low Energy Wireless Link to a Smart Phone

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***Abstract*—Behavior tracking with severely disabled children can be a challenge, since dealing directly with a child's behavior is more immediately pressing than the need to record an event for tracking purposes. By the time a paraeducator ('para') is able to break away and record events, behavior counts can be forgotten. This paper presents a paraeducator glove design that can help to track behaviors with minimal distraction by allowing a paraeducator to touch their thumb to one of their other four fingers, where each finger represents a different behavior. Count data are packaged by a micro-controller board on the glove and then sent wirelessly to a smart phone via a Bluetooth Low Energy (BLE) link. A customized BLE profile was designed for this application to promote real-time recording. These data can be forwarded to a database for further analysis. This para glove design addresses basic needs of a wearable device that employs BLE, including local data collection, BLE data transmission, and remote data recording. More functional sensors can be added to this platform to support other wearable scenarios.**

Keywords—Android, autism, disabled children, Bluetooth Low Energy, paraeducator glove, wearable technology

I. Introduction

The progress of a severely disabled child is often determined by tracking behavioral data collected during structured settings. Working with an autistic child while actively taking data is a challenge, since dealing directly with a child's behavior always takes precedence. Once a paraeducator ('para') is ready to record a behavioral event, they must turn their attention from the child to a data sheet or a smart phone. This recording process can result in a loss of student attention, and valuable instructional time can then be spent redirecting the student back to the task. To avoid this, paras often store results in memory until a recording opportunity presents itself, which can lead to unreliable and invalid data.

This paper presents an initial design for a behavior-counting glove worn by a para that can help them efficiently track a limited number of behaviors with minimal distraction by simply touching their thumb to one of their other four fingers, where each finger represents a different behavior. Count data are packaged by a microcontroller board on the glove and then sent wirelessly to a smart phone via a Bluetooth Low Energy (BLE) link. These data can then be forwarded to a database for further analysis. The following sections describe the glove design and the custom Bluetooth Low Energy (BLE) profile that was created to facilitate its use. This effort is a work in progress. Upcoming usage tests will be supported by the authors' clinical partners at Heartspring in Wichita, KS.

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II. Methods

A. System-Level Overview

A system-level view of the pareducator counting glove and its planned supporting resources is illustrated in Fig. 1. The BLE-enabled glove will be worn by the para to allow child behavior tracking in 'real time.' An iPod Touch v4 (eventually a cell phone) carried by the para will provide local data storage, and these behavior-count data will be forwarded to a database. As noted in the figure, a direct glove-to-database transfer through a local network may at some point also prove sensible.

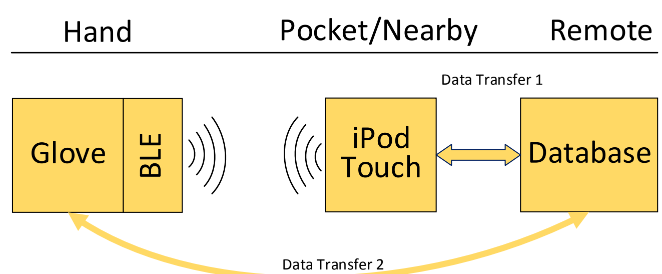

Fig. 1. Target paraeducator glove system.

BLE was chosen to transmit behavior-count data for this application since it is widely used for many portable and wearable devices, and it consumes less power in comparison to Wi-Fi and ZigBee while offering a sufficient data rate [1]. Further, the latest cell phones and tablets (both Apple and Android) also support BLE [2, 3], meaning minimal disruption in terms of the current iPod Touch units employed by paraeducators at Heartspring versus platforms they may employ in the future.

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B. *Basic Glove Requirements*

Given its role as a behavior-counting resource that will travel with a para for potentially long periods of time, the glove must meet the following basic requirements:

- *Multiple Behaviors:* Children with autism and other severe disabilities often exhibit multiple co-existing behaviors that must be tracked in tandem. A glove should be able to track at least four different behavioral counts (i.e., by touching a thumb to each of four different fingers).
- *User Comfort:* To be used daily, the glove should be comfortable to wear for long periods of time.
- *Washable:* The electronics should be easily removable or protected so the glove can be washed with other clothing.
- *Low Cost:* The glove and the supporting circuitry need to be inexpensive and easy to assemble, with the knowledge that many paraeducators have little-to-no technical training.
- *Small & Low-Power Circuitry:* The circuit hardware must be inconspicuous when placed in the glove and operate for a long time without the need for battery replacement.

C. *Glove Operation*

Fig. 2 illustrates the basic connectivity of the para glove, where a thumb touches one of four fingers to increment a behavioral count. The thumb and the (back sides of the) four fingers offer conductive pads which are connected to I/O pins of a microcontroller unit (MCU) mounted on a central board. The thumb conductor is configured as a ground reference, and the four finger conductors are set to high if not connected to the thumb. When the thumb is touched to a finger (i.e., to complete the circuit and record a count), the I/O pin connected to this finger will be set to ground, and an interrupt will be generated so that the MCU can record the count and package these data for transmission.

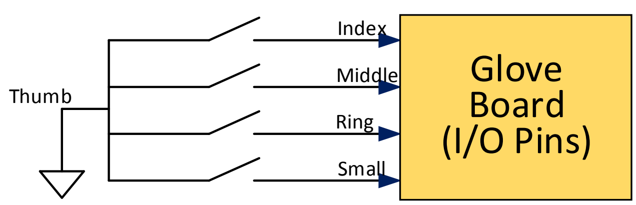

Fig. 2. Paraeducator glove operation.

D. *Current Glove*

Fig. 3 contains a picture of the current version of the para glove. Conductive-fabric pads are stitched to the tip of the thumb and to the back sides of the four fingers: locations that minimize the possibility that a thumb/finger connection will occur accidentally while a paraeducator works with a child. Conversely, the pad placement needs to be such that relatively little user effort is required to make a connection. Each conductive-fabric pad is stitched in place with conductive thread, and each thread travels along the back of each finger toward the printed circuit board.

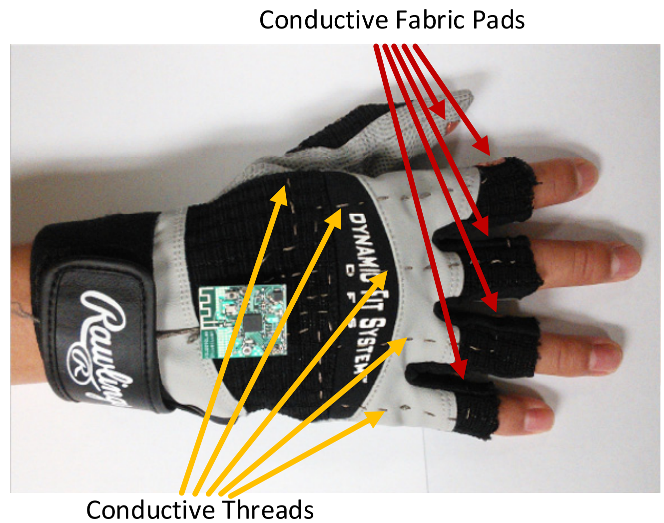

Fig. 3. Paraeducator glove conductive pads and threads.

E. *Hardware Design – Central Board*

Fig. 4 illustrates the block diagram of the para glove central board. The core chip for the central board is the CC2541 system-on-chip RF IC from Texas Instruments that offers a 2.4 GHz Bluetooth Low Energy stack, a high performance 8051 MCU for low power applications, 8 KB of RAM, 128/256 KB of in-system-programmable flash memory, and a compact 6 mm × 6 mm QFN-40 package [4]. The **BLE** block in Fig. 4 represents the BLE peripheral circuit, including an antenna printed on the board. The **Power** block is designed with a Texas Instruments TPS62730 step-down DC-to-DC converter for low power management [5]. A 3-axis accelerometer has been added to support future applications that focus on paraeducator hand movement. Fig. 5 contains photographs of the front and back of the central board.

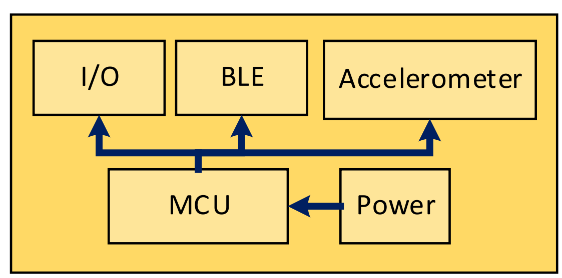

Fig.4. Central board block diagram.

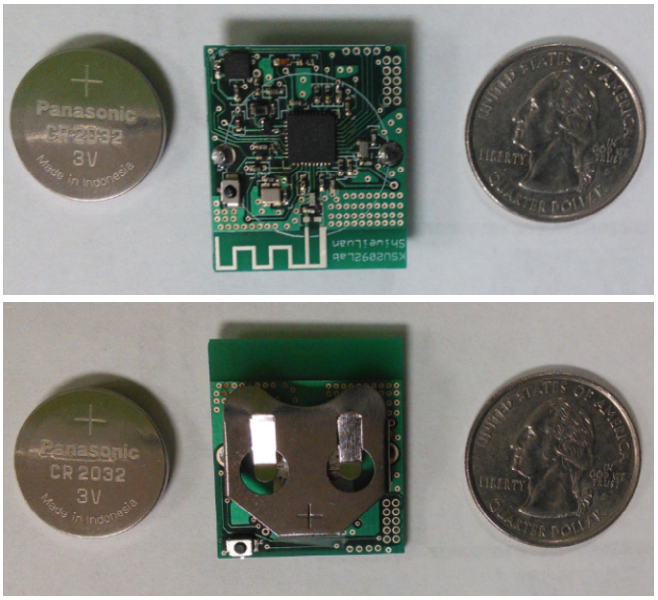

Fig.5. Top and bottom sides of the central board.

F. Bluetooth Low Energy (BLE) Profile Design

Bluetooth 4.0 Application Architecture Introduction. Bluetooth Low Energy devices can fulfil a server or client role. A server is a device that provides information for client devices, and a client is a device that requests information from a server. In this design, the para glove is a server that provides data, while an Android device is a client that receives data [6]. A server device is typically described by its profile, services, and characteristics. It can implement several profiles at the same time, where a profile is a collection of services, a service is a collection of characteristics, and a characteristic (relating to data stored) is specified by a characteristic declaration, a characteristic value, and a characteristic descriptor. BLE implements multiple layers, where a Generic Attribute Profile (GATT) layer is used to exchange data stored as a "characteristic value" between a server and client devices [3, 4]. A GATT layer is also where the para glove profile is implemented (see the next section).

Para Glove Profile Design. The TI CC2541 comes with a SimpleGATT profile for simple data transactions [7]. The para glove profile extends this profile since it needs a greater number of characteristics to store and transmit data. Table 1 lists the simplified attribute table designed for the para glove, where services are shown in yellow, characteristics are shown in blue, and characteristic values are shown in gray. The second column of each blue row defines a characteristic property of "10." That is, all characteristics use notifications to push data to a client device without a data-read request. Moreover, each characteristic defined in Table 1 is mapped to a finger connected to an I/O pin of the central board (except for the thumb, which is only a ground reference). After an interrupt is generated by touching a thumb to a finger, the MCU will set the characteristic value mapped to this finger, at which point that value will be sent out by the BLE stack since notification is enabled.

G. Android App Design

A device that supports BLE can be configured as a client device that receives and stores data from the para glove. For the current design, a Google Nexus 7 tablet running Android 4.3 is a client that receives and stores data. The Android app development was guided by literature for TI Sensor Tag Android app development, where the source code was modified to (a) be consistent with the para glove profile in Table 1 and (b) generate a different graphical user interface (GUI) [8]. Fig. 6 displays the central board linked to an Android device using BLE. Each horizontal yellow bar in the GUI represents a different finger, and the bar width maps to the number of counts affiliated with each finger.

Table 1. Simplified paraeducator glove Profile Attribute Table.

Type	Hex/Text Value	GAT Server Permissions
GATT_PRIMARY_SERVICE _UUID	0xFFE0(GLOVE_SERVICE_UUI D)	GATT_PERMIT_READ
GATT_CHARACTER_UUID	10(notify only)	GATT_PERMIT_READ
GLOVE _CHAR2_UUID	0 (1 byte)	(none)
GATT_CLIENT_CHAR_CFG _UUID	00:00 (2 bytes)	READ| WRITE
GATT_CHAR_USER_DESC_ UUID	" Char2" (6 bytes)	GATT_PERMIT_READ
GATT_CHARACTER_UUID	10(notify only)	GATT_PERMIT_READ
GLOVE _CHAR3_UUID	0 (1 byte)	(none)
GATT_CLIENT_CHAR_CFG _UUID	00:00 (2 bytes)	READ| WRITE
GATT_CHAR_USER_DESC_ UUID	" Char3" (6 bytes)	GATT_PERMIT_READ
GATT_CHARACTER_UUID	10(notify only)	GATT_PERMIT_READ
GLOVE _CHAR4_UUID	0 (1 byte)	(none)
GATT_CLIENT_CHAR_CFG _UUID	00:00 (2 bytes)	READ| WRITE
GATT_CHAR_USER_DESC_ UUID	" Char4" (6 bytes)	GATT_PERMIT_READ
GATT_CHARACTER_UUID	10(notify only)	GATT_PERMIT_READ
GLOVE_CHAR5_UUID	0 (1 byte)	(none)
GATT_CLIENT_CHAR_CFG _UUID	00:00 (2 bytes)	READ|WRITE
GATT_CHAR_USER_DESC_ UUID	" Char5" (6 bytes)	GATT_PERMIT_READ

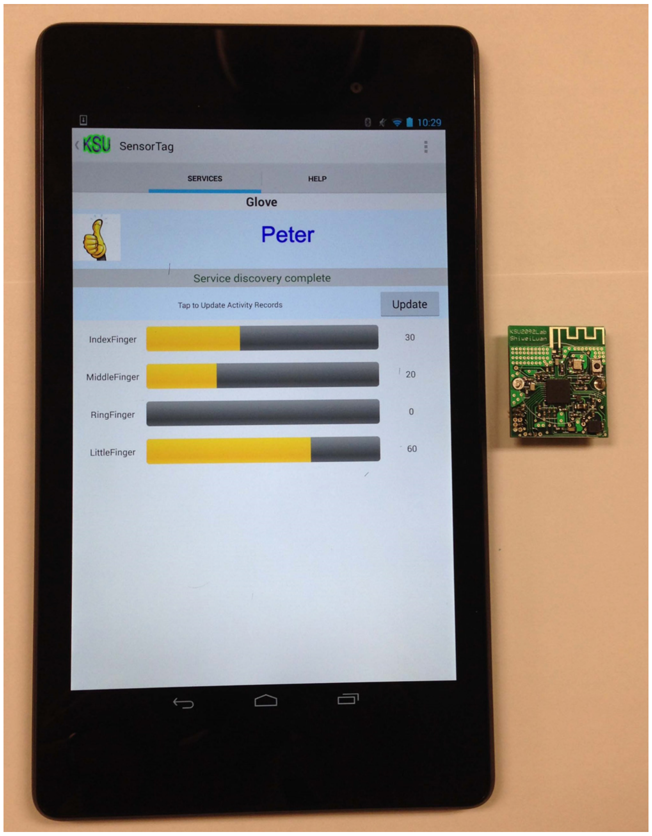

Fig. 6. Initial glove app running on an Android tablet.

III. Conclusion and Future Work

This paper presented the early design of a behavior-counting glove to be worn by a paraeducator while they work with a severely disabled child. It features conductive fabric pads, conductive thread, a compact circuit board, wireless BLE support, and an Android app to track behaviors. The design also incorporates a basic BLE application structure for wearable device design.

The current version of the glove has a few limitations: one glove can record only four behaviors, false counts can be generated from normal gestures, one glove is designed to monitor only one child, counts cannot be undone, and the para does not receive audible feedback when a count is incremented.

In future versions, conductive pad size/placement will be optimized to maximize usability and minimize false counts. If possible, pad arrays may be incorporated to support more behaviors and ideally multiple children. An 'undo' operation will be implemented, and a vibration motor, buzzer, and/or cell phone tone will be added to inform the para that a count has been registered. This latter element will also allow the para to know when a false count has been obtained. The pads (and perhaps the wires) may be replaced by conductive ink printed on glove material to make the glove more comfortable and compact. Finally, the circuitry and antenna may be mounted on flexible PCB material to improve wearability, and a smaller battery may replace the coin cell.

Acknowledgments

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References

[1] Dementyev, Artem, Steve Hodges, Stuart Taylor, and Joshua Smith. "Power consumption analysis of Bluetooth Low Energy, ZigBee and ANT sensor nodes in a cyclic sleep scenario," *Wireless Symposium (IWS), IEEE Int*, 2013, pp. 1–4.

[2] Liu Guo-cheng, Yu Hong-yang. "Design and Implementation of a Bluetooth 4.0-based Heart Rate Monitor System on iOS Platform," *Communications, Circuits and Systems (ICCCAS)*, Vol. 2, 2013, pp. 112–115.

[3] "Bluetooth Low Energy, Android Developers," 2014, http://developer.android.com/guide/topics/connectivity/bluetooth-le.html.

[4] "CC2541 2.4-GHz Bluetooth low energy and Proprietary System-on-Chip," 2013, http://www.ti.com/product/cc2541.

[5] "CC2541 SensroTag Reference Design," 2014, http://www.ti.com/tool/cc2541sensortag-rd.

[6] "Bluetooth Smart (Low Energy) Technology," 2013, https://developer.bluetooth.org/TechnologyOverview/Pages/BLE.aspx

[7] "Texas Instruments CC2540/41 Bluetooth Low Energy Software Developer's Guide v1.3.2," 2013, http://www.ti.com/lit/ug/swru271f/swru271f.pdf.

[8] "SensorTag User Guide," 2014, http://processors.wiki.ti.com/index.php/SensorTag_User_Guide#Android.