Design Projects Motivated and Informed by the Needs of Severely Disabled Autistic Children*

Steve Warren, *Member, IEEE*, Punit Prakash, *Member, IEEE*, David Thompson, *Member, IEEE*, Bala Natarajan, *Senior* Member*, IEEE*, Charles Carlson, *Member, IEEE*, Kim Fowler, *Fellow, IEEE*, Ed Brokesh, Jack Xin, Wayne Piersel, Janine Kesterson, and Steve Stoffregen

***Abstract*—Technology can positively impact the lives of severely disabled autistic children if used to (a) gather situational awareness data regarding their health, development, and behavior and (b) assist them with learning and day-to-day activities. This paper summarizes student design projects in the Kansas State University (KSU) College of Engineering that are motivated and informed by the needs of severely disabled children at Heartspring, Wichita, KS. These efforts are supported through the National Science Foundation's *General and Age-Related Disabilities Engineering* (GARDE) program. Projects relate thematically to (1) facets of a bed sensor system that unobtrusively tracks nighttime health parameters and child activity and (2) miscellaneous resources geared toward paraeducator ("para") and child well-being and development.**

I. Motivation

Autism prevalence estimates of 1 in 88 individuals [1] have been recently increased to 1 in 68 individuals [2]. Autism negatively affects social interaction and communication, and children with an autism spectrum disorder (ASD) may engage in repetitive activities, perform stereotyped movements, behave in harmful ways, resist changes to daily routines/environments, and/or offer unusual responses to sensory experiences. These children are more likely to exhibit sleep disorders (50-80% prevalence) when compared to neurotypical children of similar ages (9-50% prevalence) [3, 4], and poor sleep quality can lead to anxiety, developmental regression, and aggressive behavior [3].

Commercial assistive technology that can meet the needs of a child with ASD can be difficult to find: each child is unique and may live with concomitant disabilities. While this uniqueness can lead to caregiver frustration, it also offers a rich engineering design space. A design well-matched to a child with ASD is likely a "one of" design, increasing its appeal to an engineering student project team. This design space is under-tapped and offers students in various curricula the opportunity to design tools that offer clear and immediate benefit to these children, their caregivers, and their extended support community.

This paper summarizes student design projects in the Kansas State University (KSU) College of Engineering motivated by the needs of this autistic population. These projects are informed by paras and clinical staff that work with severely disabled children that live at Heartspring in Wichita, KS. Support for these design efforts has come from two grants funded by the National Science Foundation's *General and Age-Related Disabilities Engineering* (GARDE) program (CBET–1067740 and UNS–1512564).

II. Project Context and Approach

A. Target Population and Needs

Heartspring (Wichita, KS) is a not-for-profit therapeutic residential and day school program that provides services and therapies for children with various types of developmental disabilities. Heartspring supports 52 full-time students (ages 5 through 22) from 11 states. These children receive one-on-one paraeducator ("para") support throughout the day and stay in residential apartments at night. About 96% of these children have a primary diagnosis of autism, and 65% are non-verbal.

Interactions with Heartspring administrators, paras, and clinical staff have helped to define the design landscape germane to the needs of these severely disabled, autistic children. This design space is broad and relates to hardware, software, and processes that

- maximize the safety of these children in their residential, educational, and therapeutic environments,
- improve the delivery and effectiveness of physical, social, and cognitive therapies,
- 'quantify' these children in terms of their situation (e.g., health, behavior, and activity at all times of day) and in terms of their development within the context of their individualized education plans (IEPs) (e.g., learning, trends, outcomes assessments, and ability to perform activities of daily living),
- track children and paras within their environments to optimize facility use, improve the impact of human resources, prevent undesirable child/child interactions, and mitigate elopement, and/or
- increase the quality of life and well-being of the parents, paras, clinicians, administrators, and other service providers that work with these children.

*This research is supported by the National Science Foundation General and Age-Related Disabilities Engineering (GARDE) Program under grants CBET–1067740 and UNS–1512564.

Steve Warren, Punit Prakash, David Thompson, Bala Natarajan, Charles Carlson, and Kim Fowler are with the Department of Electrical & Computer Engineering, Kansas State University, Manhattan, KS 66506, USA (swarren/prakashp/davet/bala/cwcarl/kimrfowler@ksu.edu).

Ed Brokesh is with the Department of Biological & Agricultural Engineering, Kansas State University, Manhattan, KS 66506, USA (ebrokesh@ksu.edu).

Jack Xin is with the Department of Mechanical & Nuclear Engineering, Kansas State University, Manhattan, KS 66506, USA (xin@ksu.edu).

Wayne Piersel, Janine Kesterson, and Steve Stoffregen are with Heartspring, Wichita, KS 67226, USA (wpiersel/jkesterson/sstoff@heartspring.org).

B. Design Courses

Approximately 30 KSU engineering students and faculty have engaged with these projects each of the last few years. The venues are both formal design-project courses and informal special topics courses managed as independent design experiences:

- ECE 773 – *Bioinstrumentation Design Laboratory*
- ECE 690/890 – *Wearable Medical Devices for Disabled Children*
- BAE 536/636 – *Biological Systems Engineering Senior Design I/II*
- IMSE 591/592 – *Senior Design Projects I/II*
- ME 574/575 – *Interdisciplinary Industrial Design Projects I/II*
- ECE 571 – *Introduction to Biomedical Engineering*

III. Results from Selected Design Efforts

Design projects have addressed various needs. For the purposes of this paper, projects are grouped thematically into two areas: (1) efforts that help to realize a bed sensor suite to track nighttime parameters that indicate child well-being and activity and (2) projects that address various facets of daytime para and child well-being and development.

A. Bed Sensor Suite

Heartspring clinical staff emphasize that severely disabled children are 'wired differently' than neurotypical children, so a reliance on lessons learned from sleep studies available in the literature is not always sensible. Each child is different, so the availability of a reasonably priced, unobtrusive means to track child nighttime well-being and activity is an important step toward realizing the link between their sleep quality and daytime well-being and performance. To that end, student teams have addressed various facets of a bed sensor suite, depicted as a solid model in Figure 1. The design is based on a standard Heartspring bed: a wooden enclosure that contains space underneath that is inaccessible to the child – space that can host electronics that support the bed instrumentation. Note that this bed is designed to be an alternative to a traditional wired polysomnograph (PSG), as PSGs are not sensible with this population given the intrusiveness of their wires and support electronics. 'Surrogate' sleep quality data will be obtained with the bed sensors, and these data will be validated with commercial PSG equipment.

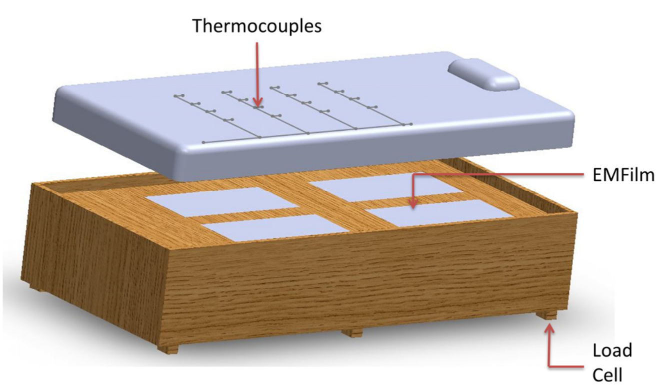

Figure 1. Depiction of the bed sensor suite.

As depicted in Figure 1, the bed employs six stainless steel **load cells** (OMEGA Engineering, LCM302-200N – see Figure 2) placed under its corners and sides to collect child location/movement data (e.g., center of position, tossing and turning, in-and-out-of-bed activity). When the child is still, these sensors can also provide ballistocardiograms (BCGs) from which heart rate and respiration rate can be extracted [5]. Figure 3 presents representative exit/entrance events gathered with each of four load cells under the corners of the bed. BCG and movement data are also acquired via four **electromechanical films** (EMFit L-Series, 300 mm x 580 mm – see Figure 2) arranged in a fitted sheet under the mattress. These film-based BCGs provide data streams from which heart rate and respiration rate can be extracted (refer to Figure 4). Child position, body surface temperature, and bed-wetting data will be acquired using a **thermocouple array** (J-type thermocouples; TC direct; #201-144) placed above the mattress and under the bed sheets. Planned upgrades include ambient signals (room temperature, humidity, pressure, light levels, and acoustic room noise).

Sensor signals are managed with a National Instruments (NI) LabVIEW virtual instrument (VI) connected to an NI 9184 cDAQ Ethernet chassis that supports an NI 9205 analog input module (load cell and film data) and an NI 9213 thermocouple module. The VI will incorporate a multi-tabbed design, where one tab will display a simple layout of child wellness indicators for use by Heartspring apartment staff. Additional tabs will present research 'dashboards' that display sensor data and parameter trends.

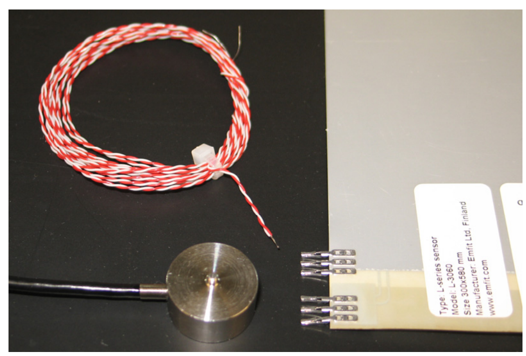

Figure 2. Load cell (lower left), thermocouple (upper left), and EM film (right) sensors employed in the bed design.

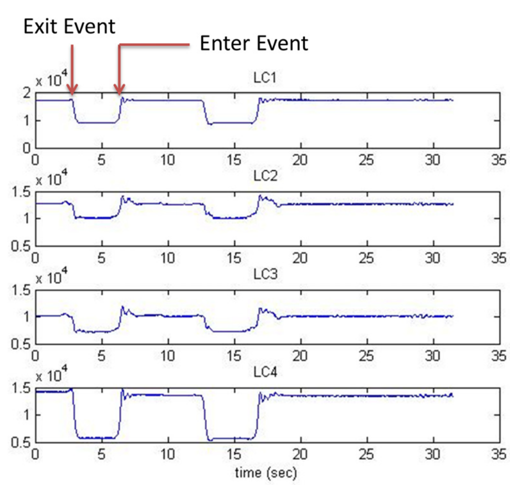

Figure 3. Example in-and-out-of-bed activity (load cells).

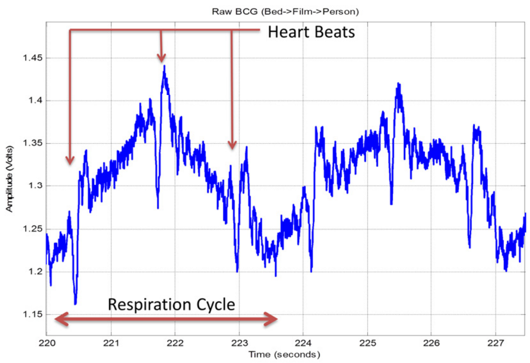

Figure 4. Unprocessed BCG data acquired with an EM film.

B. Other Student Design Efforts

Other design efforts have addressed daytime well-being, assistance, and education:

- a **behavior-counting glove** that a para can use to tally child behaviors,
- a **para-educator armguard** for bite protection,
- a **self-injurious-behavior monitor** worn by a child that can detect and count self-abuse events,
- **textile-based antennas** embedded into clothing that form wireless links for 'hidden' wearable devices,
- a force-sensor-driven **gait analysis system** worn by a child with a shoe-based orthosis,
- a **musical toothbrush** that tracks brush movement and time per location, where music provides the child with positive feedback to reinforce brushing patterns,
- **surface computer games** for social interaction training and outcomes assessment,
- a heavy duty, **adjustable stand** to safely position a large surface computer,
- **tracker tools** to determine student/para location in an indoor facility,
- Intel **Edison-based** designs for mobile sensors, and
- a wearable **galvanic skin response system** to gauge para/child emotional states.

The following text relays information for selected projects.

Behavior Counting Glove. While working with a severely disabled child, a para has the additional task of recording the frequency and type of behavior offered by the child; those data are valuable when evaluating/updating a child's IEP and their associated medications and therapies. However, behavior tracking can be a logistical challenge, since the para must deal with the behavior first and then record the event when an opportunity presents itself. If too much time has elapsed, counts can be forgotten. The goal of this design effort, first presented at EMBC 2014 [6], was to create a prototype glove that would allow a para to record behavioral counts with minimal distraction by touching their thumb to the inside of a given finger, where each of four fingers corresponded to a different type of behavior. These counts could then be automatically uploaded to the institutional database. The prototype glove and the custom microcontroller/transmitter board are depicted in Figure 5. Bluetooth Low Energy (BLE) was chosen as the wireless protocol so that these count data could be stored directly to the iPod Touch 4 units carried by Heartspring paras.

Figure 5. Behavior-counting glove and BLE wireless microcontroller board.

Adjustable Surface Computer Stand. Large-surface-computer games have been viewed as means to quantify a child's progress in specific task areas (e.g., sorting shapes, identifying objects, and recognizing emotions) as well as vehicles to help develop social skills like turn taking. A platform such as a Samsung SUR40 40" multi-touch surface computer is suitable, but the screen as quite heavy – about 80 pounds – and is typically mounted on pedestal legs like a coffee table. This might be sensible for individual children or small groups that are seated on chairs around the computer, but it is inappropriate for students that need to stand or are confined to a wheelchair or bed. A team of KSU mechanical engineering students therefore designed an adjustable stand that will allow the surface computer to be safely raised, lowered, and rotated. The stand hardware (minus the surface computer) is depicted in Figure 6. The design has been assessed for load bearing and stability, and the frame, whose core is a telescoping assembly from a sit/stand desk, has been welded and powder coated. The upper portion of the assembly rotates and includes a friction locking mechanism.

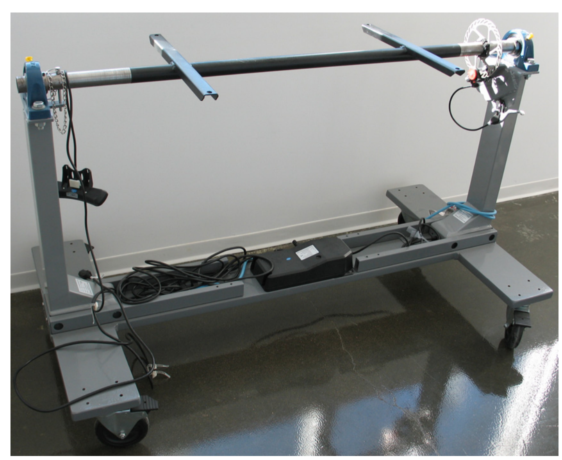

Figure 6. Adjustable surface computer stand.

Paraeducator Arm Guard. Aggression towards caregivers is common with severely disabled children, and para bite injuries incur significant medical insurance and treatment costs. The para arm guard (Figure 7) extends from the elbow to the base of the fingers and consists of three layers: an internal layer of moisture-wicking material, a middle layer of Kevlar, and an outer layer of denim. Finger holes and a cuff above the elbow keep the arm guard in place, and a Velcro strap allows the guard to be adapted for different arm sizes.

Figure 7. Para arm guard.

Intel Edison Sensor Designs. Small, wearable wireless sensing devices offer the potential to better quantify the behavior and wellness of severely disabled children. Designing such devices can be difficult for undergraduate students, because custom circuit boards are often needed to meet size constraints. The Intel Edison platform [7] offers promise as a base module for such endeavors because of its small size, processor, on-board memory, Wi-Fi/BLE wireless support, and software support. The unit is compatible with the Arduino IDE, and stackable boards with various capabilities (see Figure 8, upper) are becoming available. This platform can offer BLE connectivity to Heartspring paras' iPod Touch units that are used in various capacities throughout the day. Stackable Edison-compatible boards promises expandability to track various child parameters.

Representative Edison-based units are depicted in Figure 8. The upper portion of the figure illustrates a prototype self-injurious-behavior detection unit, consisting of an Edison unit, a base block (which supports USB devices and other serial communications), a 9DoF block (which offers a programmable inertial measurement unit with a 3-axis accelerometer, 3-axis gyrometer, and 3-axis magnetometer), and a battery block for power. Data from this stack are being analyzed to help differentiate normal movements from self-abusive behavior. The lower portion of Figure 8 illustrates a custom reflectance pulse oximeter design laid out on an Edison-compatible, stackable board. This unit is a reference design for other stackable Edison-based biomedical sensors that are under development, including electrocardiographs, electromyographs, and inductance plethymographs.

IV. Conclusion

The needs of severely disabled autistic children provide a substantive design space for engineering students. This paper addressed student-design efforts in the KSU College of Engineering geared toward quantifying the health status and development of these children and aiding their classroom learning and development. Broad student participation in these efforts emphasizes that students from various engineering curricula appreciate the opportunity to participate in design efforts with clear and immediate societal benefit.

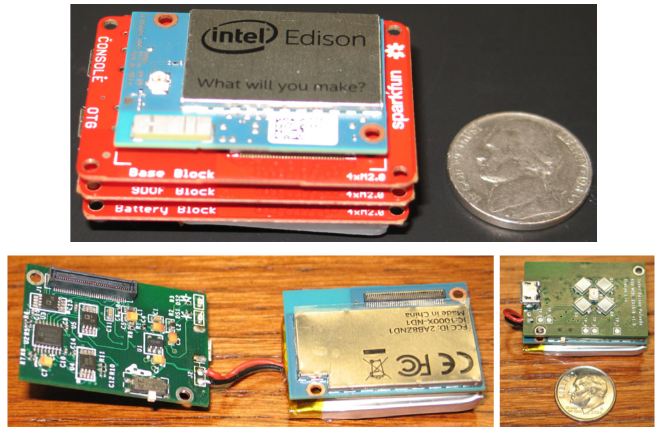

Figure 8. Intel Edison-based self-injurious behavior stack (upper) and pulse oximeter (lower).

Acknowledgments

This material is based upon work supported by the National Science Foundation *General & Age-Related Disabilities Engineering* (*GARDE*) Program under grants CBET–1067740 and UNS–1512564. Opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF. The authors acknowledge the students who provided material for the figures: load cell activity (Brogan McWilliams, Emily Schnell, and Ahmad Suliman); paraeducator glove (Shiwei Luan); adjustable surface computer stand (Aaron Dubach, Andres Orjuela, Christa Hagedorn, Derek Black, and Trevor Mader); paraeducator arm guard (Larissa Hall); Edison-based self-injurious behavior stack (Charles Carlson, Morgan Hoffman, and Austin White); Edison-based pulse oximeter (Tianyu Lin).

References

[1] "Prevalence of Autism Spectrum Disorders — Autism and Developmental Disabilities Monitoring Network, 14 Sites, United States, 2008," *Morbidity and Mortality Weekly Report (MMWR)*, vol. 61: Centers for Disease Control and Prevention, 2012, pp. 1-19.

[2] J. Baio. "Prevalence of Autism Spectrum Disorder Among Children Aged 8 Years — Autism and Developmental Disabilities Monitoring Network, 11 Sites, United States, 2010 (CDC)," *Surveillance Summaries*, vol. 63, no. SS02, pp. 1-21, March 28, 2014.

[3] S. Kotagal and E. Broomall. "Sleep in Children with Autism Spectrum Disorder," *Pediatr Neurol*, vol. 47, no. 4, pp. 242-51, Oct. 2012.

[4] A. L. Richdale and K. A. Schreck. "Sleep Problems in Autism Spectrum Disorders: Prevalence, Nature, & Possible Biopsychosocial Aetiologies," *Sleep Med Rev*, vol. 13, no. 6, pp. 403-11, Dec. 2009.

[5] O. T. Inan, P.-F. Migeotte, K.-S. Park, M. Etemadi, K. Tavakolian, R. Casanella, J. Zanetti, J. Tank, I. Funtova, G. K. Prisk, and M. D. Rienzo. "Ballistocardiography and Seismocardiography: A Review of Recent Advances," *IEEE Journal of Biomedical and Health Informatics*, vol. 19, no. 4, pp. 1414-1427, July 2015.

[6] S. Luan, D. Gude, P. Prakash, and S. Warren. "A Paraeducator Glove for Counting Disabled-Child Behaviors that Incorporates a Bluetooth Low Energy Wireless Link to a Smart Phone," *36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Chicago, IL, August 26–30, 2014.

[7] "Intel Edison - One Tiny Module, Endless Possibility," Intel, 2015, http://www.intel.com/content/www/us/en/do-it-yourself/edison.html.