The Infant Smart Anklet for Infants At-Risk of Developing Cerebral Palsy

De'Aira Bryant
College of Engineering & Computing
University of South Carolina – Columbia

Ayanna Howard, Ph.D.
School of Electrical & Computer Engineering
Georgia Institute of Technology

Abstract

The Infant Smart Anklet collects live data during an infant's spontaneous kicking movements and provides augmented reinforcement to improve their movements. This cost efficient system utilizes a sensor in the form of an anklet that sends data to a mobile app. The app then triggers a robotic mobile located above the infant when the data meets a specific threshold. This system provides a form of early intervention for infants that may be at-risk of developing motor disabilities such as cerebral palsy. The product prototype was tested on the NAO humanoid robot. The robot was programmed to simulate supine infant spontaneous kicking. The Infant Smart Anklet was placed on the leg of the robot and then monitored for accuracy, sensitivity, and reliability. It was concluded that the anklet can detect up to 94% of significant desired leg movement produced by the targeted leg.

I. Introduction

Cerebral Palsy (CP) is caused by abnormal brain development. It affects an individual's motor, cognitive, and perceptual skills [3]. Approximately 10,000 babies born each year will develop CP. It is the most common motor disability in children. The medical costs for infants with CP average about $16,721 per year, almost ten times the medical cost of infants without CP [2].

Very low birth weight infants are 24 times more likely to have CP than normal birth weight infants [11]. Providing a form of early intervention can increase the likelihood of an infant achieving significant milestones such as standing and walking later in life [4].

For infants, kicking is one of the earliest displays of motor skills [1]. Preterm infants at high risk of disability often show differences in their kicking patterns [3, 4]. Studies have shown that if these differences are identified early on, interventions may further improve the overall quality of life of the individual [9, 3]. However, these augmented interventions are oftentimes too expensive to reach the vast population that need them.

This work seeks to provide a low-cost, at home system that will help detect these abnormal kicking patterns and then provide the intervention necessary to improve them. The Infant Smart Anklet works directly with a mobile application that is linked to a robotic mobile. This system has the potential to be used by clinicians as well as parents for at-home sessions.

II. Related Work

Infant spontaneous kicking is directly related to elements of skilled coordination that are seen at later stages of life [10]. If an infant displays abnormal kicking patterns early in life, this maybe a sign that they are at risk of later developing a motor disability such as CP [4]. Studies in the past have investigated how joint trajectories of an infant's spontaneous leg movement can be analyzed and interpreted to model kicking patterns [3, 4, 7]. These findings can be used to assist in the modeling of typical infant motor development.

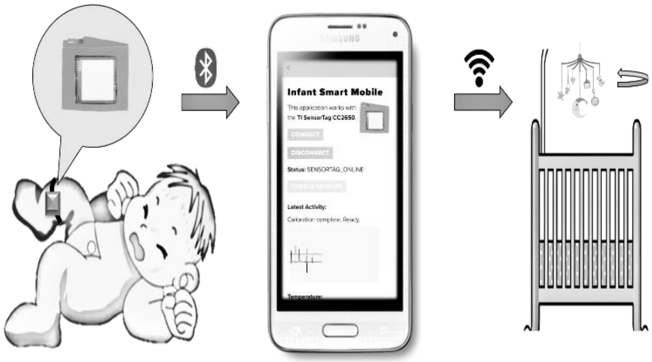


Figure 1: The Infant Smart Anklet system includes an anklet sensor, a mobile app, and a robotic mobile utilizing common bluetooth and wifi technology.

To identify and monitor these specific leg motions, several techniques have been used. Sensors have been used in the form of embedded clothing [8, 4] and wearable technology [6]. An orthotic infant suit was even created to directly manipulate the motions of the infant's legs to reduce gait deficiencies later in life [9].

Work has also been conducted that suggests an infant possesses the capability to make causal associations as early as 2 months old [5]. This has led to an increase in the use of external stimuli in current therapeutic techniques [4, 6]. In fact, when using an interactive mobile stimulated by specific leg movements, some infants were able to identify the contingency in as little as two days [6].

Another study concluded that a sensing suit could be used to stimulate a robotic mobile whenever the joint movements met identified thresholds [4]. Mobile play reinforcement has had positive results in previous studies; however, the current cost of such technologies remain out of reach for most families. This work seeks to develop a low-cost solution that incorporates mobile reinforcement with coordinated sensing designed for at-home use.

III. Methodology

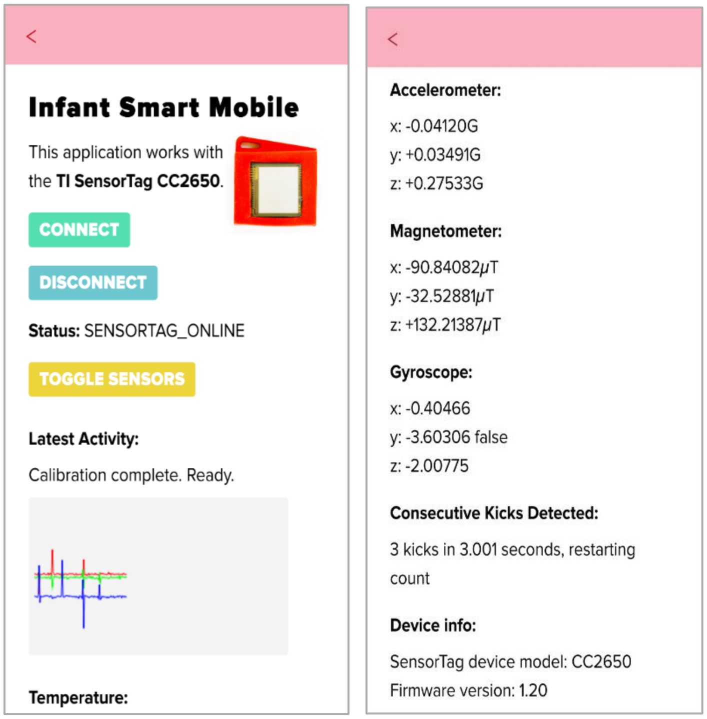
The objective of this work was to develop a system that would incorporate affordable sensors into a wearable anklet that would trigger a robotic mobile in response to an infant's supine spontaneous kicking patterns. The developed prototype includes a wearable sensor anklet to be placed on the targeted leg of the infant, a mobile application to intake and analyze the data from the anklet, and a robotic mobile to be placed above the infant as seen in figure 1.

A. *Product Development*

The following section outlines the hardware, software, and algorithms used to create the current prototype of the infant smart anklet.

Figure 2: Sensor Anklet on NAO Humanoid Robot

Anklet Hardware: The wearable sensor anklet incorporates the Texas Instruments CC2650STK SensorTag as seen in Figure 2. This sensor utilizes Bluetooth Low Energy (BLE) technology along with iBeacon technology to transfer sensor data between applications. The sensor provides valuable 3-axis acceleration and gyroscope data to be interpreted by the mobile application. The SensorTag also includes a range of other functionality that was not integrated into this project such as temperature and humidity metrics. Texas Instruments also produces a Devpack Watch screen that can be used with the SensorTag. This screen was incorporated into the design so that a parent or clinician could view the sensor's battery level, power status, and connection status.



Infant Smart Mobile

This application works with the **TI SensorTag CC2650**.

Status: SENSORTAG_ONLINE

Latest Activity:

Calibration complete. Ready.

Temperature:

Accelerometer:

x: -0.04120G
y: +0.03491G
z: +0.27533G

Magnetometer:

x: -90.84082μT
y: -32.52881μT
z: +132.21387μT

Gyroscope:

x: -0.40466
y: -3.60306 false
z: -2.00775

Consecutive Kicks Detected:

3 kicks in 3.001 seconds, restarting count

Device info:

SensorTag device model: CC2650
Firmware version: 1.20

Figure 3: Screenshots of GUI for Smart Anklet mobile app

Mobile Application Software: The Infant Smart Anklet mobile Android application was developed through Evothings Studio and Apache Cordova. Evothings Studio is a mobile application platform for cloud-connected sensors. Apache Cordova is a build system that allows the development of mobile applications using HTML, Javascript, and CSS. An open-source SensorTag mobile application was modified to fit the functionality of the Infant Smart Anklet. The current application has the capability of receiving live acceleration and gyroscope data from the sensor anklet, visualizing the data into a graph for the user of the application, analyzing the data in the background, and triggering the mobile in response to the predetermined thresholds.

A subject matter expert (SME) conducted a usability evaluation of the prototype. The SME was a certified clinician. The evaluation resulted in new additions to the prototype. These additions allowed the user to adjust the speed of the mobile and the frequency of its activation. With the new settings, the user would have the capability of adjusting the application to suit the needs of the targeted infant.

The revised prototype also informs the user of how many consecutive and total kicks are detected within a specific session. When the session is complete, the user is prompted to email sensor data for user records and further analysis. The graphical user interface for the application can be seen in Figure 3.

Kicking Detection Algorithm: The algorithm used to detect kicking can be visualized through the flow chart in Figure 4. Sensor data is imported from the sensor at a specific time step, in this case each second. For the first ten seconds of the program, the program runs a calibration function. The user is instructed to hold the infant's legs still until the calibration has completed. The calibration function intakes these values that represent no movement in order to create thresholds. The thresholds are based on the variance of sensor data from the no-movement calibrated mean. After calibration has completed, sensor data is continuously streamed and analyzed in the background. If the data meets the flags set forth in the accelerometer and gyroscope functions, kicking is detected and the mobile is triggered.

Robotic Mobile: The robotic mobile was created using littleBits cloudBit. These hardware pieces make it possible to connect virtually any object to the internet. Using a kit designed to create a remote control crib, the mobile was altered to accept HTTP GET and POST requests from within the configured mobile application. When the server connected to the mobile receives a request from the app via wifi, the mobile begins to spin.

B. Prototype Testing

To initially test the prototype of the Infant Smart Anklet, a NAO humanoid robot was used. The NAO has 25 degrees of freedom and stands about 58cm tall. The NAO robot's range of motion, petite size, and programming structure made it ideal to develop a program that would simulate infant spontaneous kicking. The program was created using the Choregraphe software through timeline and key-frame elements. The NAO robot was used over a course of ten trials where the Infant Smart Anklet was placed on the left leg of the robot. The trials were used to measure to accuracy, frequency, and reliability of the prototype system.

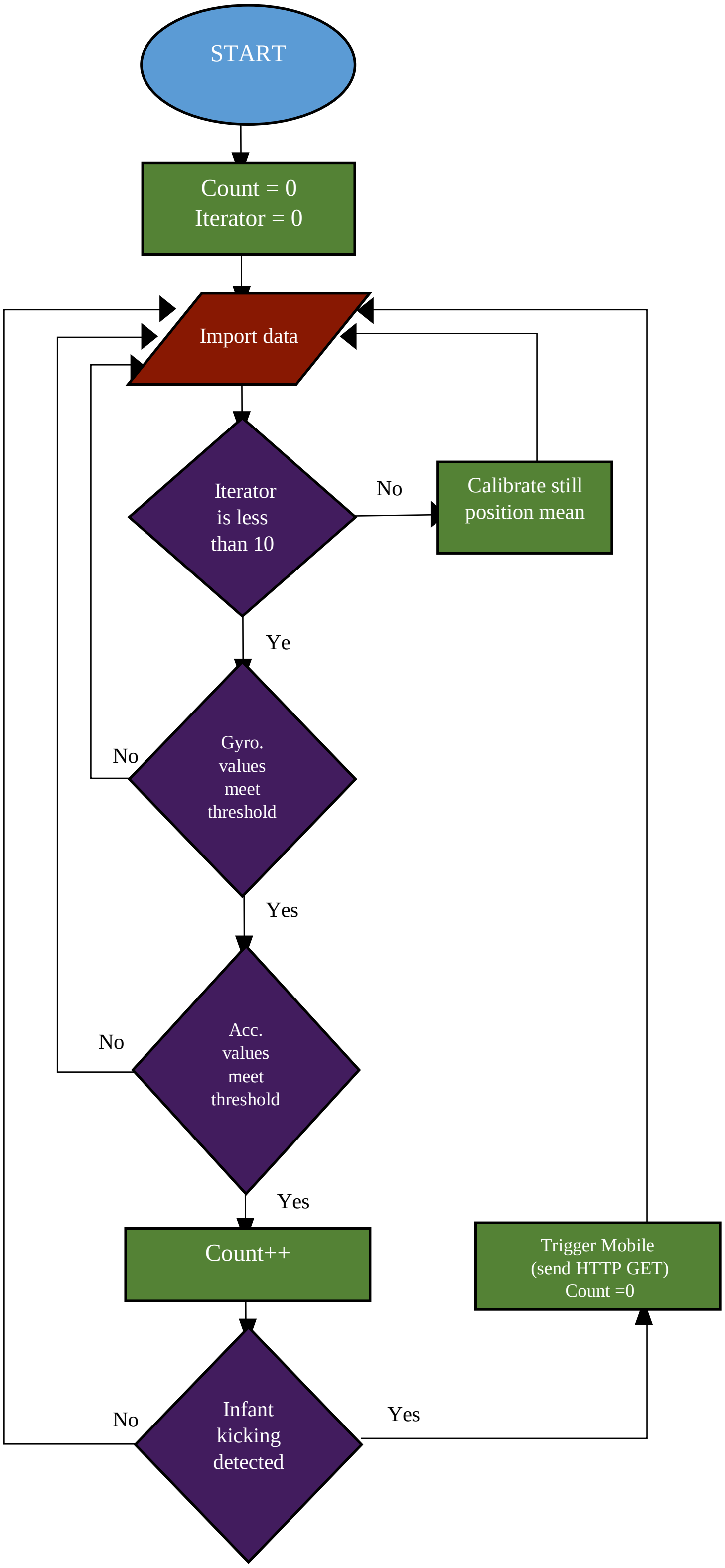


Figure 4: Kicking detection algorithm flow chart

Infant Kicking Simulation with NAO robot: To better simulate the variances of infant spontaneous kicking, several videos of infants kicking were watched and coded to create the list seen in Table 1. The ten variances encompassed nearly all of the leg motions shown in the videos of infants kicking. Software was then developed for the NAO robot to kick, modeling the ten variances of infant spontaneous kicking. The NAO was also programmed to incorporate random eye, head, and arm movements to further simulate an infant’s movement during testing. The program was designed so that the NAO would randomly choose one of the ten variances of infant kicking every few seconds until each of the ten variances had been executed. The order of the kicks was shown in the console screen for the researcher’s documentation.

Prototype Trials: Once the supine spontaneous kicking program had been created, ten trials were conducted using the Infant Smart Anklet system. The anklet was placed on the left leg of the robot as seen in Figure 2. For each trial, the program was executed and each of the kicking variances were monitored and recorded for detection. The results of the trials are examined in the next section.

All Kicking Variances
Alternating Kick[1,2]
Right Kick
Left Kick[1,2]
Wide Kick[1,2]
Right Leg Lift
Left Leg Lift[1,2]
Alternating Leg Lift[1,2]
Low Intensity Kick[1]
Left Half-Kick[1]
Right Half Kick

Table 1: Kicking Variance Classification.
1: Left Leg Specific Kicking Variances.
2: Significant Left Leg Specific Kicking Variances

IV. Results

The frequency of detection in relation to each kicking variance can be seen in Figure 5. When the sensor anklet was placed on the left leg, very little right leg-specific movement was detected. It was also noted that low intensity movement such as low intensity kicks and half kicks were not detected as frequently as normal kicks or lifts were.

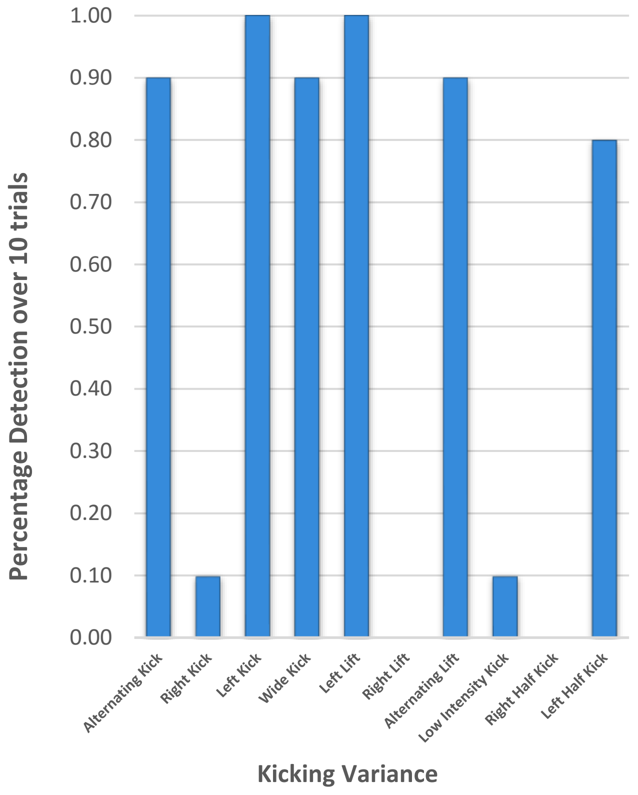


Figure 5: Kick Detection Frequency by Kicking Variance

A sample of the acceleration data provided from one of the trials is sown in Figure 6. The trigger line represents when the data met the thresholds necessary to trigger the robotic mobile. The graph illustrates the two axes of importance, X and Z. In an attempt to target model kicking motions, the Y axis was excluded from the kicking detection algorithm.

The data provided from the ten trials using the NAO humanoid robot executing supine infant kicking showed that the Infant Smart Anklet system detected approximately 55% of all kicking variances, approximately 80% of all left leg specific kicking variances, and approximately 94% of all significant left leg specific kicking variances. The robotic mobile was activated each time a kick was detected.

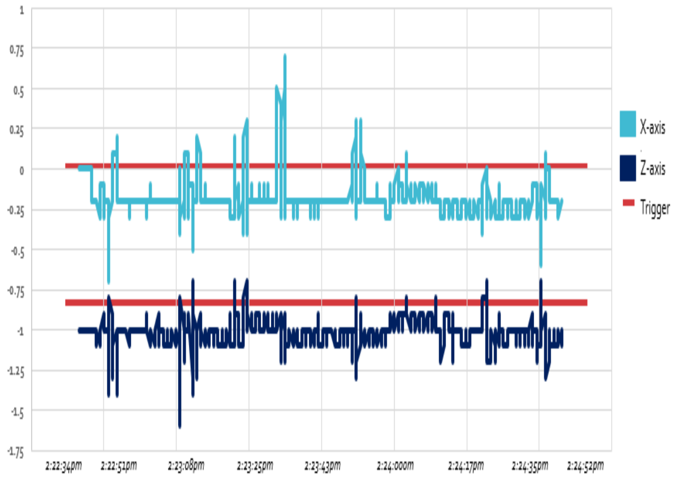


Figure 6: Acceleration data of trial 1 with mobile trigger lines. Trial 1 was conducted with anklet on left leg of NAO robot.

V. Discussion & Conclusion

As the system was designed with a target population of parents and clinicians, the current prototype is intuitive to use and extremely affordable. Assuming that the user has access to an infant crib and mobile android device, the total cost of the Infant Smart Anklet System is approximately $150. The system effectively detects significant leg movement of the targeted leg where the anklet is placed. Given the cost and accuracy of the system, the Infant Smart Anklet system could be used as an early intervention treatment for infants that are at risk of motor developmental delays. Future work consists of testing the system on human subjects. Future studies may also further investigate incorporating a second anklet to retrieve sensory information from both legs simultaneously.

VI. Acknowledgements

This work was made possible by the Distributed Research Experience for Undergraduates (DREU) program sponsored by the Computing Research Association – Women (A-W), the Coalition to Diversity Computing (CDC), and the National Science Foundation (NSF). The project was conducted through the HumAnS Lab at the Georgia Institute of Technology under the leadership of Dr. Ayanna Howard. The Infant Smart Anklet Project is a component of the larger Infant Smart Mobile Project. The researchers involved include Janelle Boyd, Jgenisius Harris, and Michelle Smith. Our very patient graduate student mentor was Sergio Garcia.

VII. References

[1] Haywood, K., & Getchell, N. (2009). *Life span motor development*. Human Kinetics.

[2] Kancherla, V., Amendah, D. D., Grosse, S. D., Yeargin-Allsopp, M., & Braun, K. V. N. (2012). Medical expenditures attributable to cerebral palsy and intellectual disability among Medicaid-enrolled children. *Research in developmental disabilities*, *33*(3), 832-840.

[3] Olsen, M. D., & Paulsen, R. R. (2016). Motion Tracking of Infants in Risk of Cerebral Palsy. Kgs. Lyngby: Technical University of Denmark (DTU). (DTU Compute PHD-2015; No. 393).

[4] Rogers, E., Polygerinos, P., Walsh, C., & Goldfield, E. (2015). Smart and Connected Actuated Mobile and Sensing Suit to Encourage Motion in Developmentally Delayed Infants. *Journal of Medical Devices*, *9*(3), 030914.

[5] Rovee-Collier, C. (1999). The development of infant memory. Current Directions in Psychological Science, 8(3), 80-85.

[6] Sargent B, Schweighofer N, Kubo M, Fetters L (2014) Infant Exploratory Learning: Influence on Leg Joint Coordination. PLoS ONE 9(3): e91500.

[7] Serrano, M., Chen, Y., Howard, A., & Vela, P. (2016) Lower Limb Pose Estimation for Monitoring the Kicking Patterns of Infants.

[8] Smith, B. A., Trujillo-Priego, I. A., Lane, C. J., Finley, J. M., & Horak, F. B. (2015). Daily Quantity of Infant Leg Movement: Wearable Sensor Algorithm and Relationship to Walking Onset. *Sensors*, *15*(8), 19006-19020.

[9] Subramanyam, K., Rogers, E., Kulesza, M., Holland, D., Gafford, J., Goldfield, E., & Walsh, C. (2015). Soft Wearable Orthotic Device for Assisting Kicking Motion in Developmentally Delayed Infants. *Journal of Medical Devices*, *9*(3), 030913.

[10] Thelen, E., Skala, K. D., & Kelso, J. S. (1987). The dynamic nature of early coordination: Evidence from bilateral leg movements in young infants. Developmental Psychology, 23(2), 179.

[11] Vincer, M. J., Allen, A. C., Joseph, K. S., Stinson, D. A., Scott, H., & Wood, E. (2006). Increasing prevalence of cerebral palsy among very preterm infants: a population-based study. *Pediatrics*, *118*(6), e1621-e1626.