Robotic Crawling Assistance for Infants with Cerebral Palsy

David P. Miller,[1] Andrew H. Fagg,[1] Lei Ding,[1] Thubi H. A. Kolobe,[2] Mustafa A. Ghazi[1]
[1]University of Oklahoma College of Engineering, Norman, OK
[2]University of Oklahoma Health Sciences Center, Oklahoma City, OK

Abstract

Infants at risk for cerebral palsy are at a severe disadvantage in learning to crawl as compared with typically developing infants. An assistive system is being created at the University of Oklahoma to improve these children's crawling abilities. The infants are: outfitted with a suit that allows kinematic reconstruction of their movements; EEG monitoring of their neural responses; and placed in an assistive robot that can amplify the effectiveness of their crawling actions and reduce the required weight bearing for successful prone locomotion. The system can also map their attempted motions into a library of recognized movements, and create directed robot motion even when the subject has not generated any propulsive forces on their own.

Motivation

Cerebral Palsy (CP) is a common physically disabling condition for children in the United States. Estimates of prevalence vary between 3 to 10 out of 1,000 children depending on gestational age at birth (Anderson, Doyle, and the Victorian Infant Collaborative Study Group 2003). CP is characterized by atypical patterns of movement associated with inadequate muscle force production, incoordination, poor temporal and spatial organization of muscle and joint activity, and postural instability. Sensory deficits in proprioception, tactile discrimination or vision also interfere with a child's ability to select appropriate movement strategies (Hadders-Algra 2001; Hadders-Algra et al. 1999). Of the numerous complications often experienced by children and adults with CP, the most disabling is mobility. The problems with mobility do not only disrupt functional independence across the lifespan but are also associated with the high cost of CP.

System Technologies Overview

We have created a robotic system, the SIPPC3 (see Figure 1(a,b)), to help children with CP develop prone locomotion skills (crawling). The system consists of the robot, a kinematic capture suit (see Figure 2), an EEG monitoring system (see Figure 3), and control/logging stations for the EEG, robot and suit. A subject is placed in the kinematic suit and EEG net, and then placed on the SIPPC3. The robot supports the subject at a desired height or percentage of their weight. Forces exerted by the subject are detected by the robot and appropriate movements of the system take place. Simultaneously, the limb and trunk motions of the subject and the subject's brain activity are captured by the suit and EEG respectively.

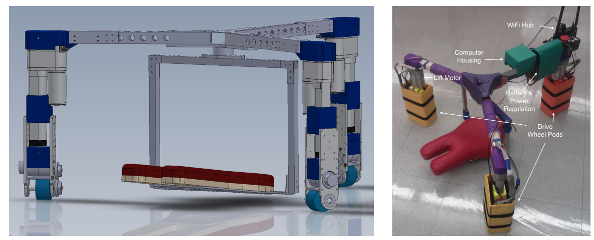

Figure 1: *(a) SIPPC3 CAD; (b) Robot Actuators*

Electroencephalography (EEG)-based neuro-imaging is used to monitor the progression of the infants development beyond kinematic data. The hypothesis is that the degree of proficiency of learned goal-oriented movement skills can be identifiable using the EEG index related to motor output. This information will be used to trace the development of motor functions in both typically developing babies and those at risk of CP while using the SIPPC3. The Mu rhythm for typically developing babies presents a shift in frequency from the delta to alpha bands along with the maturation (Berchicci et al. 2011). We are using the Mu rhythm as the EEG index to evaluate the longitudinal development of motor functions for these SIPPC3 users.

Our goal with the kinematic suit is to enable the infant to trigger robot movements through crawling-like actions, even when their limbs are not in contact with the ground.

Our approach is to sense the configuration of the infant's limbs and trunk in real time using a kinematic suit (Figure 2) that consists of 15 inertial measurement units (IMU) from CH Robotics, LLC. Three IMUs are mounted to each of the limbs (upper leg, lower leg and foot), and three IMUs are mounted to the trunk (hips, back and head). The IMUs provide orientation in 3D at 50Hz. Through a standard sensor/skeletal model, sensor orientations are translated into positions and orientations of each of the modeled body

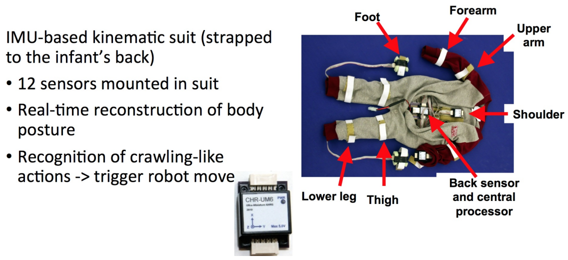

Figure 2: *Kinematic suit for gestural recognition (Southerland 2012)*

segments, including the feet, hands and head (Southerland 2012).

Actions are recognized using a set of heuristically-derived rules, each of which consists of: 1) an allowable position and velocity of a subset of the limbs, 2) a priority, and 3) a robot response (forward, backwards, turn left or right).

Related Work

There have been a number of robotics approaches to assist infants with Cerebral Palsy to obtain mobility. Some researchers have created robots that the infant can ride, (Smith, Stansfield, and Dennis 2011), which, while potentially giving the child some sense of independent mobility, does not develop any motor skills or have any of the other benefits of physical activity. Schoepflin, (Schoepflin 2010), working with somewhat older children (3-4 years) developed an assistive device more similar in action to a robotic pedal cart. Children in a sitting position activate and control the cart (a seat mounted on a Pioneer robot platform) by using a pedaling-like motion. (Kolobe et al. 2007) describes some earlier, related, work in prone locomotion. This earlier SIPPC could amplify some of the movements initiated by the child, but the fixed height put children in an advanced crawling position, regardless of their age or crawling developmental stage.

Children with or at risk of CP may have reduced muscle strength, including the diaphragm, and they may tire more readily than normally developing children. and therefore may not be able to generate the forces required to transport the body during crawling. Our robotic assistant needs to allow children to be in the prone position, and be as close to the ground as possible, while still providing adequate support for breathing. The robot should be able to assist the child in weight bearing. A crawling infant may use just their arms, legs or coordinated action amongst all four of their limbs when moving, and so the robot should be able to move the child in any direction and rotate around any point. The robot should also be able to constrain those movements and points of rotation in order to encourage more productive crawling behavior. The robot also needs to be able to handle children of different sizes and weights. Finally the robot needs to give the subject a clear view of where they were headed, and access to objects (e.g., toys) in the environment ahead of the child, so that they could plan and execute goal-driven movements (McEwan, Dihoff, and Brosvic 1991).

Robot Structure, Electronics and Capabilities

The mechanical structure of the robot is designed around an infant support platform. This is mounted to a Y-shaped central frame with three motion control modules or "legs". The infant support platform is a frame with a padded base on which an infant can lie down in a prone position. The padded base is tilted up by 7^o to get the infant shoulders and hips correctly oriented. The padded base is attached to the frame with velcro to allow for adjustments needed to accommodate various infant sizes and positions and also allows for easy removal of the padded base for transport and sanitizing. The 6 DOF FT sensor with integrated electronics (Parmiggiani et al. 2009)(fts) is the mechanical interface between the infant support platform and the central frame.

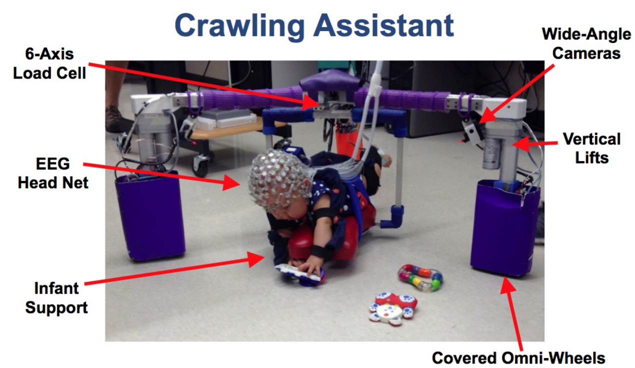

Figure 3: *SIPPC3 Crawling Assistant System in Use*

The legs are mounted at the ends of the central frame. Together, the legs provide 4 DOF motion for the infant support platform: one for raising the platform off the floor, and three for moving it in x, y, and yaw around the z axis. Each of the legs contains a linear actuator (see Figure 1) that can extend to raise the infant support platform. Built-in potentiometers in each actuator provide position feedback. The actuators are not backdrivable so they do not consume power to maintain a given height, nor will they suddenly move if power is removed.

The electronic subsystems comprise an onboard WiFi hub, an interface server, a control server, motion control "leg" modules, and a FT sensor (Figure 4). These communicate over three different physical layers: ethernet (using TCP-IP), I2C, and Controller Area Network (Bosch 1991). Ethernet connects the Interface Server, the Control Server and the Kinematic-Suit to the WiFi hub. An I2C bus links the three leg modules and control server. CAN bus connects the Control Server to the FT sensor.

This robot allows shared and dynamically changing weight bearing and it can adjust the height of the baby from approximately 3cm (the thickness of the infant support pad) to 10cm off the ground. Together these features enable the robot to accommodate infants of wide range in height and weight and let them develop their crawling capabilities in a close to natural pose from scooting along the ground to advanced crawling. The holonomic motion capability allows the robot to accommodate turns and motions that are gener-

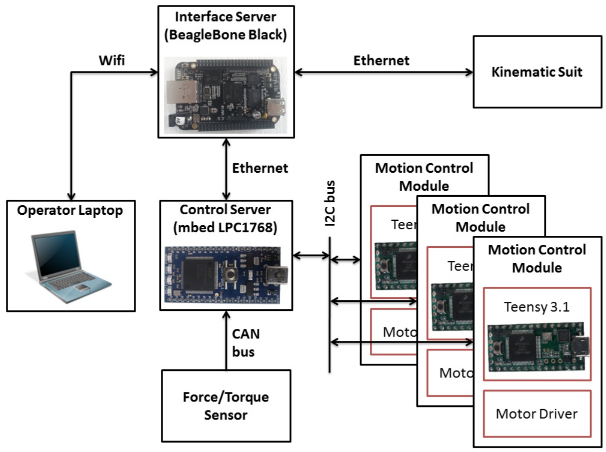

Figure 4: *Overview of the control electronics.*

ated by the subjects. The SIPPC3 body also serves as an advantageous mounting point for cameras to record head, arm and foot movements. These are new capabilities for assistive crawler robots and allow the subjects to learn and develop their prone locomotions skills more naturally.

Preliminary Results

The robot is currently in use in a study that, when completed, will test 30 typically developing infants and 20 infants at risk for CP over the next twelve months. Three typically developing infants have completed the study so far using this robot. Subjects start at four to five months and have multiple sessions per week with the robot for the subsequent eight weeks. The subjects are able to learn how to engage the robot in order to reach toys that have been placed for them on the ground.

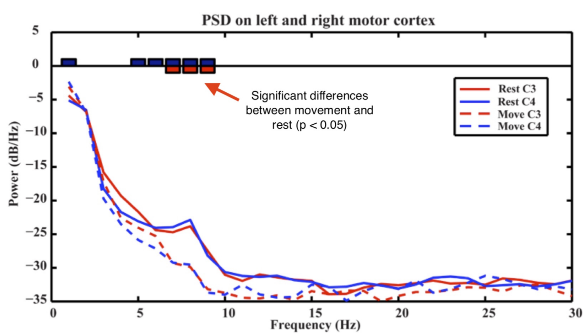

Figure 5: *Overiew of the control electronics.*

Suppression of the mu rhythm in the motor cortex has been shown to indicative of goal-directed activity. We would expect the mu rhythm to be suppressed as infants are actively engaged on the robot, as compared to when they are at rest. Some preliminary EEG data is shown in Figure 5. Rest and move data is separated by analysis of synchronized the kinematic suit data. This data is indicative of infants using the robot being able to engage in goal-directed activity.

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