Design of a Joystick with an Adjustable Damper to Study Kinematically Constrained Movements made by Children

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ABSTRACT
The aim of this work was to create an apparatus that will allow for the study of sensorimotor control development in children, specifically the interaction with a simple kinematically constrained object. A one-degree-of-freedom rotational joystick was built, sensorized with an encoder and force/torque sensor, and outfitted with a custom damper. The damper was modeled as having a stiffness, viscous friction, and Coulomb friction, and this allowed for a controlled manner by which to identify three unique damping levels. Future work will discuss the experimental setup in more detail, and will present results for how both children and adults interact with the testing apparatus. Given here is the motivation for this research direction, a brief overview of the experimental apparatus and setup, and a high-level discussion of a human subject study that will be presented in future papers.

Index Terms: H.5.2 [Information Systems]: User Interfaces—Haptic I/O; H.5.2 [Information Systems]: User Interfaces—Evaluation Methodology

1 INTRODUCTION
During the first years of one’s life, gross motor skills develop as the newborn learns to crawl, sit, stand, and finally walk. Still it takes many more years in childhood and early adolescence until specific movement patterns such as throwing and catching mature [8]. Similarly, the brain goes through an extraordinary growth at the beginning of life followed by a continuing evolution until adulthood. Primary sensory and motor areas associated with basic functions are the first to develop, followed by areas involved in spatial orientation and language until 11-13 years of age, and, finally, areas involved in executive function like integrating information from the senses and reasoning in late adolescence [3, 15]. Both genes (nature) and environment (nurture) interplay to determine one’s growth [5], yet the contribution from each factor to sensory, motor, and cognitive development has yet to be clearly understood. More recent work demonstrates that one’s body also plays an important role, and the current dominant view of motor development is the so-called dynamic perspective where “movements are a product of the central nervous system, biomechanics and energetic properties of the body, environmental support, and specific demands of the particular task” [14].

2 SCIENTIFIC MOTIVATION
The motivation for this research is to better understand how humans develop the skills required to reach adult-like levels of proficiency in sensorimotor tasks throughout the childhood and adolescent years. In particular, the aim is to understand how children learn to control the interaction force with a kinematic constraint when manipulating articulated objects. This is important because many everyday actions, such as opening a door, involve kinematic constraints. An understanding for how normal development occurs can be useful for diagnosing and possibly enhancing the rehabilitation treatment for those experiencing compromised sensorimotor control capabilities.

In adults, studies have examined how forces are applied against the constraints of a kinematically constrained object [7, 10, 11, 13]. From a motor control perspective, these tasks raise interesting questions because the constraint might have both positive and negative effects. On the negative side, forces applied against the kinematic constraint constitute a waste of energy since it does not contribute to the movement. This seems to be the case when considering, for example, the relatively large force applied by users in the radial direction when rotating a crank [13]. On the other hand, it has also been suggested that the control of the movement might be simplified by taking advantage of kinematic constraints [7].

To the best of our knowledge, no similar study has been conducted with children. Most developmental research with young-age children to-date has focused on tasks such as reaching and grasping (e.g., [4, 6]). This research has shown that after the first year of life the infant has relatively good grasping abilities but is not yet able to truly manipulate objects, while the skill of drawing and writing with a mature hand posture is acquired by 6.5 years of age [12]. Even so, the control of the gripping force is not as skilled in children as in adults, even for simple grasps [2]. Development of haptic and motor skills is incited through the interaction with more haptically complex toys, as noted by observing that children use more mature grasping movements when playing with a toy that has moveable parts than with a simple cube [1].

One puzzling research question is explaining why developmen-
3 Design of the Joystick

This work presents the development of a passive force feedback system that allows for the safe study of how children learn to interact with forces and control movement strategies when manipulating a kinematically constrained object. To that end, we built a one-degree-of-freedom sensorized joystick that allows measurement of the interaction forces when the joystick is manipulated (see Figures 1 and 2). Given that the device needs to be used by young children in schools, it was designed from the onset to be portable, sturdy, and simple to use. The decision to build a setup rather than to use commercially-available haptic devices comes from the fact that portable haptic devices cannot implement very rigid constraints. For simplicity’s sake, we also made the decision not to include any motor in the setup and to use, instead, a custom-designed settable mechanical damper to manipulate the amount of force required to move the joystick. The setup uses technology developed for a humanoid robot [9], specifically its sensors, communications, and control card, which allowed for easy usage in terms of data transmission and overall system compactness.

3.1 Testing Apparatus

The sensorized joystick was developed to be kid-safe, with sensors that are sensitive enough to measure the child’s interaction while sturdy enough that they do not break under a possibly aggressive movement. The device is a custom-made passive one-degree-of-freedom mechanical device that allows for a rotation about a single axis, this being the \( x_{\text{Origin}} \) axis as displayed in Figure 2. The resulting motion is similar to rotating a joystick on a gambling slot machine. An overview of the mechanical components is indicated in Figure 1.

Both a position and force sensor were incorporated into the mechanical design to allow for the measurement of the user’s interaction. Position was sensed via an AEDA-3300-TAT encoder (Avago Technologies; San Jose, California, USA), which was attached to one end of the rotating shaft. Force was measured via a 6-axis force/torque sensor, IIT FTSens (Istituto Italiano di Tecnologia; Genoa, Liguria, Italy), which was attached orthogonal to the rotating shaft at a distance of 0.0165 [m] from the device’s axis-of-rotation. The user interacts with the system via a 0.040 [m] diameter sphere that is indirectly connected to the force/torque sensor. The center of the sphere is located at a distance of 0.120 [m] from the device’s axis-of-rotation.

An aim of the setup was to display differing levels of frictional torque. Therefore, a custom mechanical damper was included in the design. Much care was required to develop a damper that could effectively apply a constant frictional torque that was independent of the joystick’s angular position. The damping level was controlled by using a dynamometer to rotate the dynamometer adjustment screw to a fixed torque setting.

A plastic cover conceals the mechanical and electrical components of the system from view and has a thick slot within which the handle rotates. The range of permitted motion is \( \pm 90^\circ \), where 0° is defined as when the handle is perpendicular to the base. An Ethernet Motor Supervisor (EMS-001) card (Istituto Italiano di Tecnologia; Genoa, Liguria, Italy), which was attached orthogonal to the rotating shaft at a distance of 0.0165 [m] from the device’s axis-of-rotation, communicates the measurements from the encoder and FTSens via an ethernet cable to a Dell XPS M1330 laptop (Dell Inc.; Round Rock, Texas, USA).

3.2 System Response

Figure 2 identifies the forces and torques that will be quantified to describe how a human interacts with the joystick. Energy exerted that does not assist in achieving the rotary motion of the joystick is indicated by the red arrows.

Data from an example interaction with the joystick are shown in Figure 3, specifically the position of the joystick and torques applied in the constrained (\( \tau_x, \tau_y \)) and unconstrained directions (\( \tau_z \)) as a function of time (with respect to the origin coordinate frame). For this example, torques were applied about the Y-axis that reached nearly 2.5 [Nm]; this exerted effort did not provide any assistance for rotating the joystick.

We save an in-depth presentation about the system for a future article in which analyses will include identifying its inertial and gravitational contributions.
3.3 Damper Characterization
An aim of this work was to model the damper’s response in a controlled manner that would allow for a comparison of user interactions across trials. Numerous models were tested, and the model that we selected had an offset ($\beta_0$), spring ($\beta_1$), Coulomb friction ($\beta_2$), and viscous friction ($\beta_3$):

$$\tau(t_i) = \begin{bmatrix} 1 & \frac{\theta(t_i)}{|\theta(t_i)|} & \dot{\theta}(t_i) & \frac{\dot{\theta}(t_i)}{|\dot{\theta}(t_i)|} & \theta(t_i) & \dot{\theta}(t_i) \end{bmatrix} \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} + [\varepsilon_i], \quad i = 1, \ldots, n \quad (1)$$

where $\tau(t_i)$ is the resistive torque applied by the custom damper (units of [Nm]), $t_i$ is the time at the discretized instant $i$, $\theta(t_i)$ is the angular position of the device (units of $^\circ$), $\frac{\dot{\theta}(t_i)}{|\dot{\theta}(t_i)|}$ is the sign of the joystick’s rotational velocity (unitless value of $-1$, $0$, or $1$), $\dot{\theta}(t_i)$ is the joystick’s rotational velocity (units of [m/s]), and $\varepsilon_i$ is the unexplained noise in the torque signal (units of [Nm]).

Data at absolute velocity values less than $10$ [°/s] were removed from the analysis, and a multiple linear regression was run to obtain a fit for the unknown parameters. The behavior of the mechanical damper and the modeled fit across three damping levels is shown in Figure 4. We postpone further discussions about the damper’s behavior and the model selection process for another article.

4 CONCLUDING REMARKS
Future presentations of this material will include a more thorough discussion of the hardware and design choices, and a system characterization describing the joystick’s behavior. Additionally, the device presented here will be incorporated into a human subject study to ask questions such as whether young children are able to manipulate the joystick in the most efficient manner. That is, do children rotate the joystick in the non-constrained direction, or are they expending energy by pushing the joystick along the constraints (e.g., against the black casing in Figure 1), which does not provide any added benefit for completing the task. The manner by which children interact with the system will be presented as a function of one’s age.

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REFERENCES