Developing Soft Lossy Force Sensors for Detection of Infant-Toy Interactions

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Abstract

Early identification of neurodevelopmental disorders in infants is crucial for timely intervention to improve long-term functional outcomes. Feasibility trials have established differences in toy interaction behaviors between healthy and at-risk infants. The proposed smart toy aims to improve quantitative measurements of these interactions to detect risks of developing motor delays. Utilizing a unique configuration of soft lossy force sensors, the toy shows promise in classifying toy interactions such as grasp, hit, squeeze, kick etc.

Introduction

- In the United States, one in ten infants is born prematurely [1]; preterm birth is strongly associated with a risk of neurodevelopmental delay [2].
- Due to the high neuroplasticity of infants, rehabilitation has been shown to be especially effective before the age of 2 [3].
- Current clinical assessments of infant motor ability, specifically risk of cerebral palsy, like the Test of Infant Motor Performance and the General Movements Assessment, are qualitative and less accessible [4].
- This toy is a part of the Play and Neuro Development Assessment (PANDA) Gym, an interactive, universal, portable, quantitative, and affordable assessment tool to detect neurodevelopmental delays in infants (Fig. 1).
- **Objective: To optimize the design of novel lossy force sensors with a newly designed "Soft" toy and electronics to classify and distinguish infant-toy interactions**

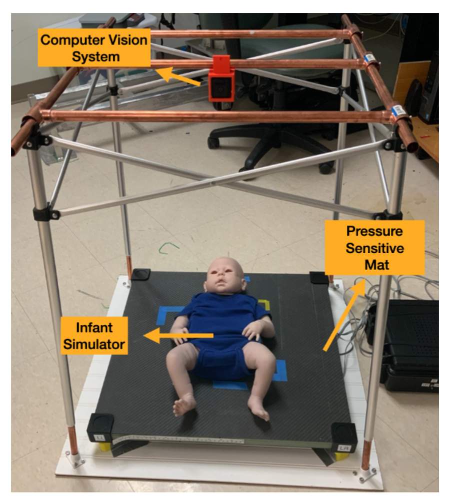


Fig 1. PANDA Gym

Previous Toy Iteration: Ailu

Fig 2. The PANDA toy, Ailu

- The most recent iteration of the PANDA gym toy, Ailu, aimed to measure pressure applied to the arms and face (Fig. 2) [5]
- NeoPixel lights in the ears and dynamic audio sounds attracted infant attention (Fig. 3)
- Silicon rubber arms with pressure transducers measured pressure up to 137.9 kPa (Fig. 4)

Fig 3. Neopixel lights in ears

Fig 4. Silicone ring tube inside arms of toy to measure grasping forces

- To sensorize the face and ears, a pressure-sensitive conductive sheet was sandwiched between conductive fabric, creating a custom-sized force-sensitive resistor (FSR).

Limitations

- After testing Ailu with numerous healthy and premature infants, the following limitations were discovered:
- **Robustness:** the custom-made FSR's weren't durable and came apart after multiple uses
- **Reliability:** due to the lack of durability of the FSR's, the face and ears were ineffective at collecting consistent data
- **Depth:** Ailu was able to differentiate interactions between the face, arms, and either ear but lacked detailed information on classifying interactions by type

Lossy Sensor Development

- Principle: light traveling through optic fiber is lost due to bending [6]
- Laced jewelry string, which emulates a cost-effective optic fiber, through structure
- Force applied to structure correlates to bending of string and, thereby, loss of light (measured by photodiode) → **"lossy"** sensor
- Utilized a truss-shaped lattice structure to weave the fiber through to ensure even spread of force (Fig. 5)
  - Lattice structure was printed from Flexible 80A resin on FormLabs Form 3B+ printer
  - Ideal material properties (Shore A Hardness value of 70A [7]), enabling the structure to be soft and elastic, yet firm

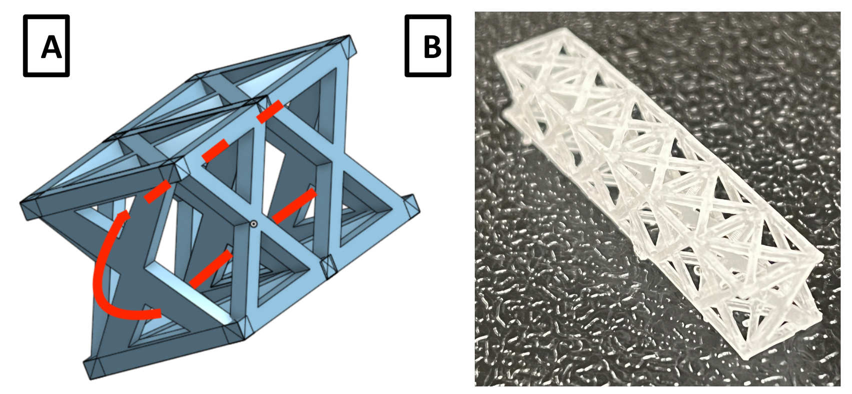


Fig 5. **A.** Lattice structure unit model with optic fiber (jewelry string) in red. **B.** Close-up of printed lattice structure

- Arms: hexagonal lattice structure designed for multi-directional sensing of grasping forces, also printed in Flexible 80A resin (Fig. 6)

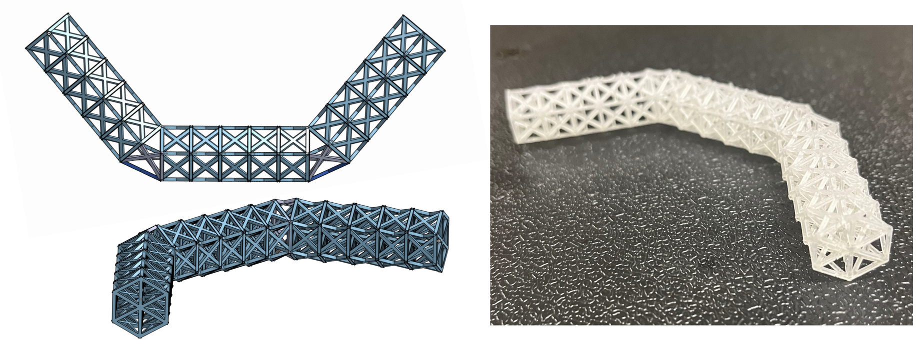


Fig 6. Views of model and printed arm lattice

- Designed and resin-printed mount for fiber and LED/Photodiode (Fig. 7)

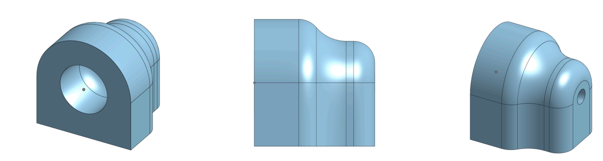


Fig 7. Views of LED/Photodiode mount

Toy Development and Testing

Body Design

- Functionally, the toy is similar to Ailu in overall shape (Fig. 8), which was based on U.S. Consumer Product Safety Commission Age Determination Guidelines for Children's Toys [8]
- Evaluating feasibility of lossy sensors; will incorporate feedback mechanism and look of Ailu in final product
- Body was 3D-printed in ABS

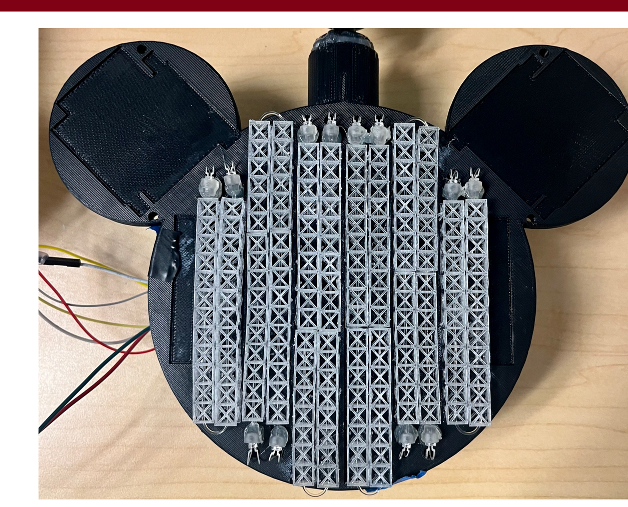


Fig 8. Front view of new sensorized PANDA toy without arms

Electronic Design

- For robust, repeatable testing, developed printed circuit board (PCB) to fit meshly into face, incorporating 12 individual sensors (Fig. 9)
- Each sensor combines an IR LED emitter with a photodiode, along with corresponding components for signal amplification (Fig. 10)
- Used the Teensy 3.2 microcontroller to connect to, control, and read signals from the PCB sensors

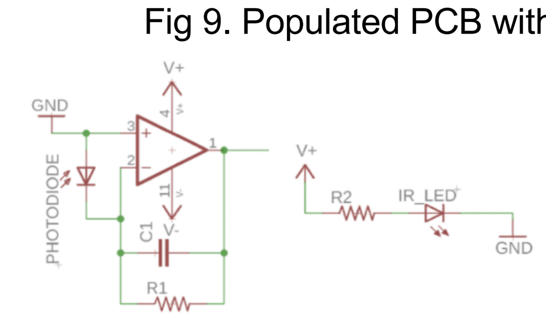
Fig 9. Populated PCB without LED/PDs

Classifying Interactions

- Four types of force sensor voluntary interactions by infants to classify: Touch, Kick, Weaker Grasp, and Stronger Grasp (Table 1) [9]

	Low Force	High Force
Low Duration	Touch	Kick
High Duration	Weaker Grasp	Stronger Grasp

Table 1. Proposed Classification of Interactions



R1	1MΩ
C1	4700 pF
R2	220Ω
V	4.5V

Fig 10. Sensor circuit diagrams

Testing

- Analyzed analog values for consistency, important characteristics
- Force Testing
  - Used Instron Model 4444 mechanical tester to measure force while collecting sensor data from one sensor as a sample (Fig. 11)
  - Used analog force gauge to measure force while collecting sensor data across the whole face

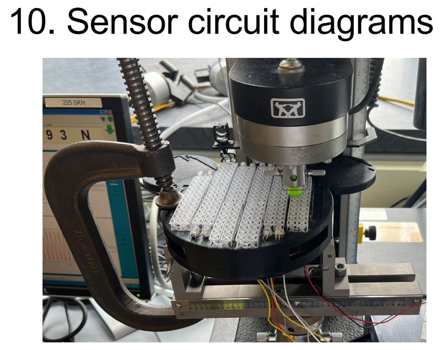


Fig 11. Instron testing of lossy sensors on toy

Results and Discussion

- Lattices on the face use six sensors, which correspond to six analog signals (Fig. 12)
- Longer sensors have more length for light to be lost, yielding lower baseline values and, potentially, decreased sensitivity
- "Low" and "high" durations of forces classified by thresholding peak widths

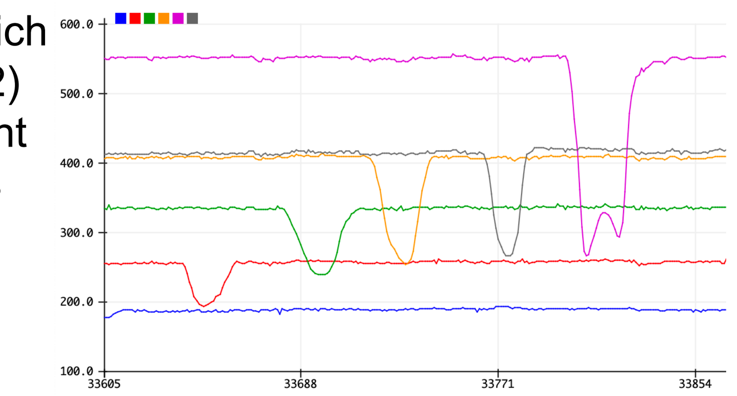


Fig 12. Sample sensor signals, minima peaks corresponding to applied forces

Instron Testing (Fig. 13)

- Gradient Boosting regression for predicting force from prominence value yielded avg. MSE of 0.188 N and avg. R-squared of 0.493 (n=100), indicating low error but not an amazing approximation
- Issue: deformation from rapid, successive testing

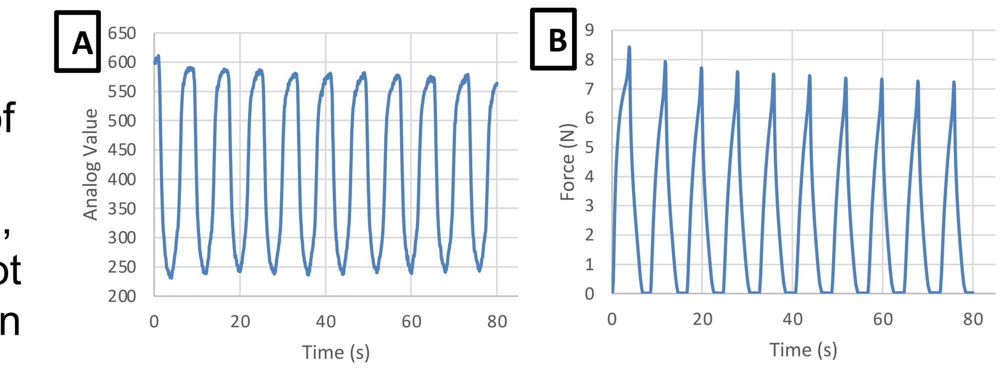


Fig 13. **A.** Sample sensor data during Instron testing. **B.** Corresponding force data from Instron

Force Gauge Testing

- Relative signal change (RSC) plotted against force (Fig. 14)
- Logarithmic trendline fitted to data
- RSC = 0.0592 * ln(Force) – 0.0633
- R-squared: 0.605 → reasonable

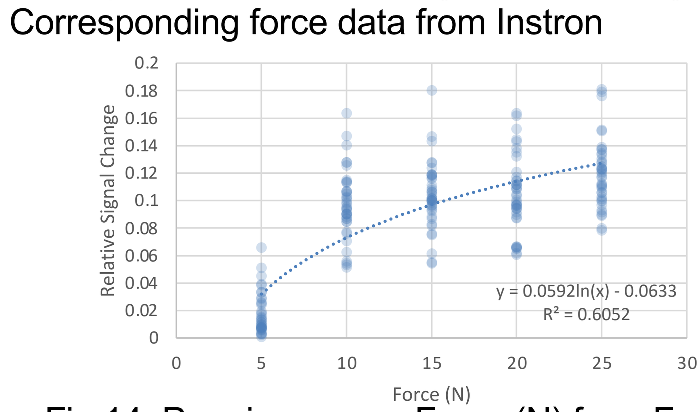


Fig 14. Prominence vs. Force (N) from Force Gauge Testing

Ongoing/Future Work

- Collecting ground truth data on the four types of interactions to build robust model that **directly classifies interaction**
- Toy mounted to stand for testing (Fig. 15)
- Add in lights and sounds from Ailu to capture infant attention
- Add fabric and stuffing
- Incorporate all electronics inside the toy with no hanging parts

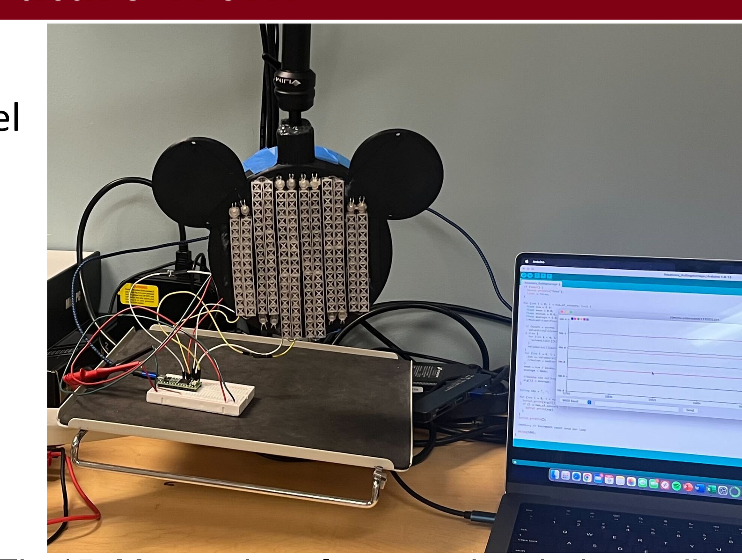


Fig 15. Mounted toy for ground truth data collection

Acknowledgments

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