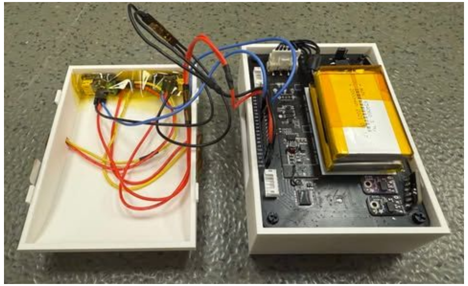
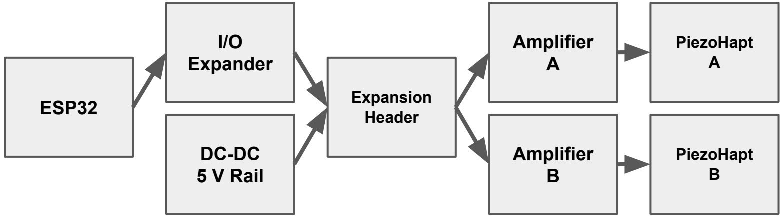
Handheld Hardware

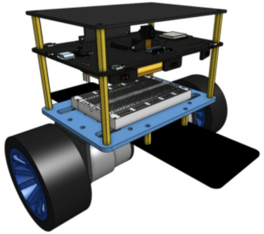
- Biped motherboard taken straight out of a Biped chassis.
- Identical hardware architecture as Biped.
- PiezoHapt amplifiers connected to the expansion header on the Biped motherboard driven by its secondary digital I/O expander.
- Custom designed, 3D printed enclosure which puts everything together.

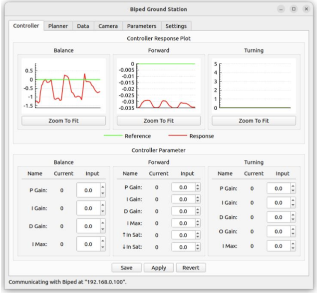




Handheld Software

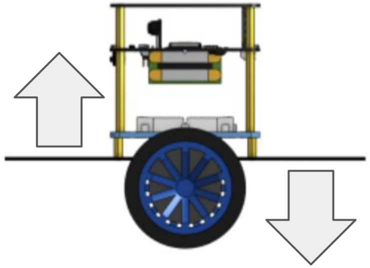
- Based on the same Biped firmware used to control and balance Biped.
- Modified to receive telemetry from Biped on the ground.
- Received telemetry used to drive PiezoHapt actuators and generate haptic feedback.
- Haptic signal generated by a real-time task controlled by a hardware timer.

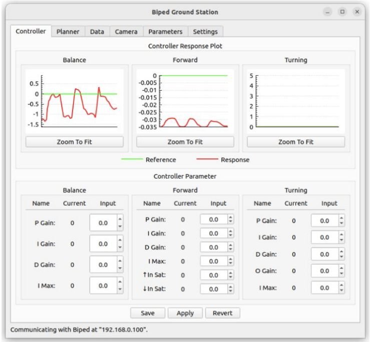




Proposal: Haptic Controller Fine-Tuning

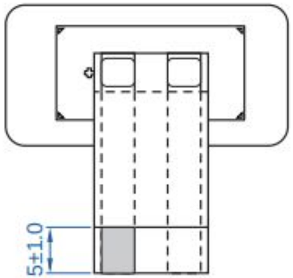
- Currently, CS 431 students are able to tune the PID controllers by 1): visually examining Biped’s reaction (oscillations, etc.) and 2): visually examining the controller response plots on the ground station.
- Nevertheless, it is sometimes difficult to gauge the effects of a parameter change even by examining the plots (difficult to perceive the scales).
- Therefore, what if students can actually “feel” the controllers’ performance?
- **Proposal:** Use controller response plot waveforms to drive haptic actuators and help users to feel the subtle differences in controller performance.

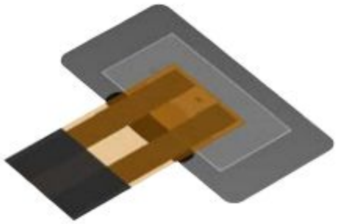




Haptic Actuator

- PiezoHapt actuators driven by two digital amplifiers.
- Work by applying voltage to its terminals, causing its internal material to bend, thus generating tactile feedback.
- Thin, provide wide frequency response ranging from 2 Hz to 300 Hz and beyond, and their outputs are still perceptible even when tightly squeezed.





Evaluation: Preliminary Testing

- Conducted initial self-evaluation with three team members.
- Fine-tuning without haptic feedback was slow and imprecise due to a lack of intuitive error indicators .
- Using the haptic actuator, users were able to perceive error magnitude more easily, allowing for faster and more confident adjustments.
- Tactile cues provided real-time feedback, reducing dependence on visual monitoring and enhancing situational awareness.
- “Feels like you are on the Biped.”

Evaluation: Future Experimental Study

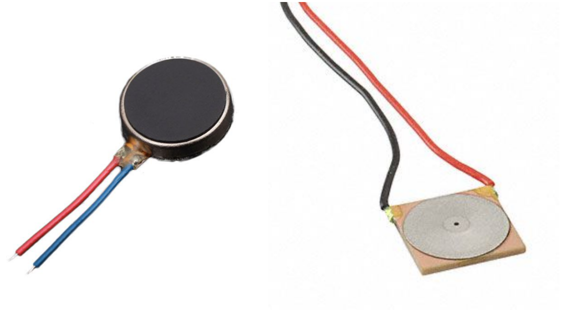
- Plan to conduct a controlled psychophysical study:
  - Two participant groups: with and without haptic feedback.
  - Record time to convergence, final error, and parameter tuning efficiency.
- Hypothesis: Participants using haptic feedback will achieve quicker and more accurate tuning outcomes.
- Include participants with visual impairments to assess accessibility benefits.

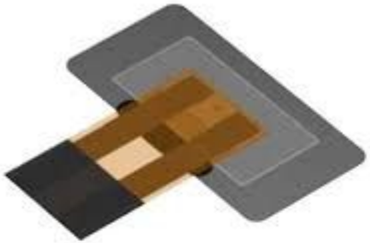
Evaluation: Measurement & Questionnaire Plans

- Use sensors to quantify actuator output:
  - Measure actual frequency, amplitude, and latency of tactile signals.
- Post-task questionnaire themes (Likert scale & open-ended):
  - Effectiveness of actuator in detecting and reducing error.
  - Ease of use and intuitiveness of feedback.
  - Fatigue and cognitive load comparison.
  - User preferences and suggestions for improvement.

From Proposal to Prototype

- Actuator selection:
  - Piezo disk (SEN10293).
  - Piezo buzzer.
  - Piezo (PHUA3015-30A-21-000).
  - Vibration motor.
  - Audio speakers.
- Signal to perception:
  - AM ended up not working too well.
  - FM worked well.
  - Frequency selection:
    - Lower frequency range, from 0 - 100 Hz, worked well.
    - Anything around 200 - 300 Hz was difficult to distinguish.
- Biped motherboard to actuator:
  - H-bridge from biped did not work well.
  - Audio amplifier (PAM8904).
- System response:
  - Biped balancing control.
  - Position control response.
  - Multiple response characteristics.
  - Single steady-state error.





Prototyping Experience and Future Directions

- Surprising preliminary results
  - Multi-sensory feedback with loud clicks from the actuator.
  - Feeling of “having your hand on the biped”.
- Everything come together well in the end hardware-wise
  - The piezo amplifiers worked well with the 5 V rail of the biped.
  - The piezo actuators worked really well and gave clearly distinct feelings.
- Changes and improvements
  - Ergonomic handheld enclosure for mouse-like use.
  - Alternate modes for additional response characteristics (overshoot, settling-time, etc.)
  - Mapping for different control systems (ambiguous feeling for biped balancing).

Conclusion and Takeaways

- Haptic feedback improved fine-tuning accuracy and speed.
- Made PID tuning more intuitive and accessible.
- Real-World Applications:
  - Medical robotics: surgical tool calibration.
  - Drones: tuning flight stability controllers.
  - Industrial machines: real-time error feedback during maintenance.
  - Assistive tech: feedback for users with low vision.
  - Automotive systems: tactile tuning of steering or lane assist PID.