# Improved Continous Tactile Feedback on Trunk Posture

## Story of my thesis

- Started thesis with this belt feedback topic
- Was difficult to execute, prototyping hardware did not exist for wearables
- Built a lot of hardware, ended up with the shoe project (see thesis draft)
- Left Canada for Germany, resumed working on belt work, thinking it might be easy to wrap up
- Turns out, its a different thesis, though now we have the hardware to built the prototype we were missing in the beginning
- Advice from thesis supervisor (canada) is to write minimal thesis around a core contribution
- I think the contribution would be in teasing out something from the tactile actuators (Tactors) we have now, as opposed to the vibration motors we used to have – both are in the belt and thus ideal for a comparison study.
- Did a lot of baseline measurements of the actuators
- Built a evaluation system for the hip-tilt-task (below)

## Intro (2)

Vibrotactile (VT) actuators have become ubiquitous, but their applications rarely venture beyond notifications through simple buzzes. One promising avenue for use of vibrotactile signals is in closed-loop feedback systems. Examples include videogames, telemanipulation, navigation, supporting graphical interfaces, but also physical therapy, which we chose as our example application. One well-studied case are feedback belts for balance training, where four (or more) tactors provide a real-time vibrotactile display of the wearer's hip orientation to facilitate motor learning.

Here, we compare the characteristics of two respresentative tactors: vibration motors / Eccentric Rotating mass Motors (ERM) and the Lofelt Sound Engine voice coil (VC) tactor. In existing VT feedback systems, the tilt angle is commonly mapped to tactor vibration amplitude; mostly tactors are the ERM type, which implies a frequency-amplitude coupling. Feedback based on pulses of varying lengths seems promising as it minimizes sensory adaptation (HAPI) but has not been studied for balance feedback, but for posture guidance (HAPI). One issue is that the necessary signal synthesis has prevented wider adoption of VC tactors in research, and the most common open-loop control of ERMs limits pulses to low frequencies as the motors rotation only slowly fades out. Recently, closed-loop control ICs have become available, promising to enable a more fine-grained control for pulsing stimuli for ERMs as well.

### Research Questions

This motivates our primary question here: Are ERMs, with suitable control, capable of coming close to the more expensive voice coil tactors, or does the Lofelt's higher temporal resolution enable measureable performance improvements? This would enable potentially more comfortable, salient displays on low-cost tactors.

In the following, we begin with quantitative analysis of the two tactors type addressing the following research questions.

- What are the physical limits of the two tactor types integrated into a balance belt?
  - Frequency response
  - Shortest pulse length
  - Highest pulse frequency
- What are the perceptual limits?

These findings inform the stimuli for a user study on VT feedback for hip orientation, where :

- Which posture-vibration mappings are most effective?
  - Activation strength vs. pulse vs combined?
  - What makes a stimulus more comfortable, which mappings are more and less fatiguing, and other subjective / qualitative aspects communicated by users
  - Improved task performance: time to target / trajectory length / error / attempts / trajectory around target

### Meta

- Break apart the problem into steps that generate insights
- Goal is to provide groundwork for improved systems, basic science rather than applied, going into the perceptual real
- Contribution should be a solid basis, demonstrating science craftmanship and laying foundation for future work
- Writing inspiration: https://www.frontiersin.org/articles/10.3389/fnrgo.2021.678981/full

### Related Work (2)

- → Summarize the state of art on continous VT feedback for posture
- → Application Overview

### Actuators Overview (2)

- → copy from brix paper
  - ERM
  - Lofelt
  - Drive

### Example Application: Hip tilt feedback

Wall, Sienko and Bao's work on VT belts for balance feedback demonstrated that providing feedback on trunk orientation during physio-/occupational therapy excercises is beneficial, showing improved functional assessment scores. As it is impractical and premature to replicate such longitudinal (6-8 weeks) studies with patients in a real rehabilitation scenario, we present a proof-of-principle study on healthy adults with target-seeking task.

The participants are asked to tilt their hips to reach a predefined pan/tilt target, assisted by decreasing tactile feedback.

#### Balance Belt Apparatus (1)

Our VT feedback belt is built to be comparable to Bao's system, using the BRIX5 prototyping system described in detail elsewhere. It combines four tactor units and an orientation sensor on an adjustable, stretchable belt. The tactor units consist of one cylindrical ERM and one Lofelt tactor with miniaturized amplifier, and are placed in the four ordinal directions (front left/right, back left/right). We measure absolute orientation is using a BNO080 orientation sensor placed on the small of the back on the belt. Its best-in-class sensor fusion provides stable roll/pitch/yaw mesurements from fused accelerometer/magnetometer readings without drift. The belt is worn on the height of the pelvis (also suffers least from breath interfering with orientation sensing). In feedback mode, motion in roll/pitch is indicated with activation of two actuators For this study, the belt is connected through a through 3m tether to a personal computer with: USB-Audio + SuperCollider for Lofelt synthesis and user study interface; ERM driver and microcontroller; BNO-readout microntroller, and Python glue for interfacing and static measurements.

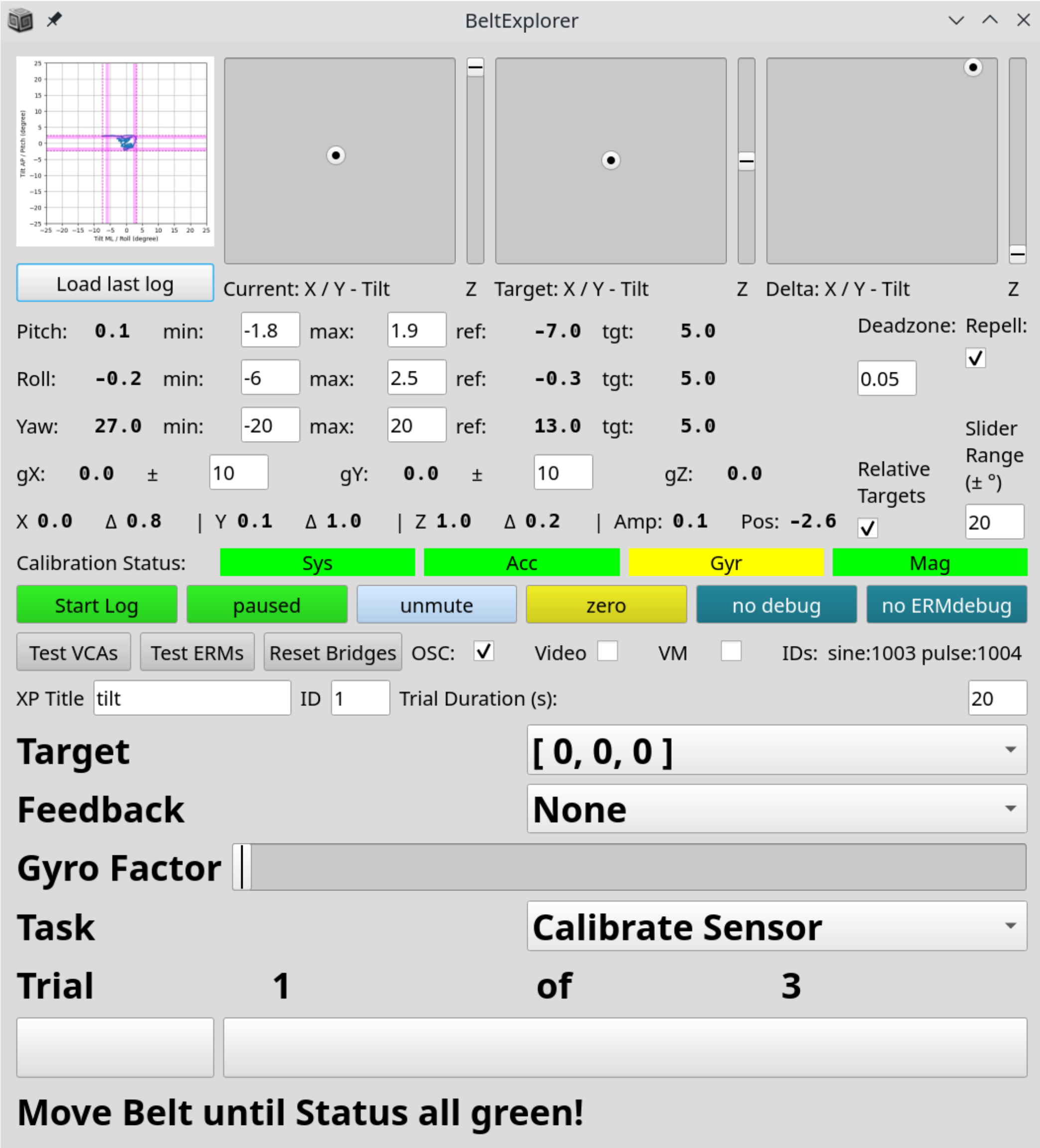


Figure 1: Belt System Experiment Software

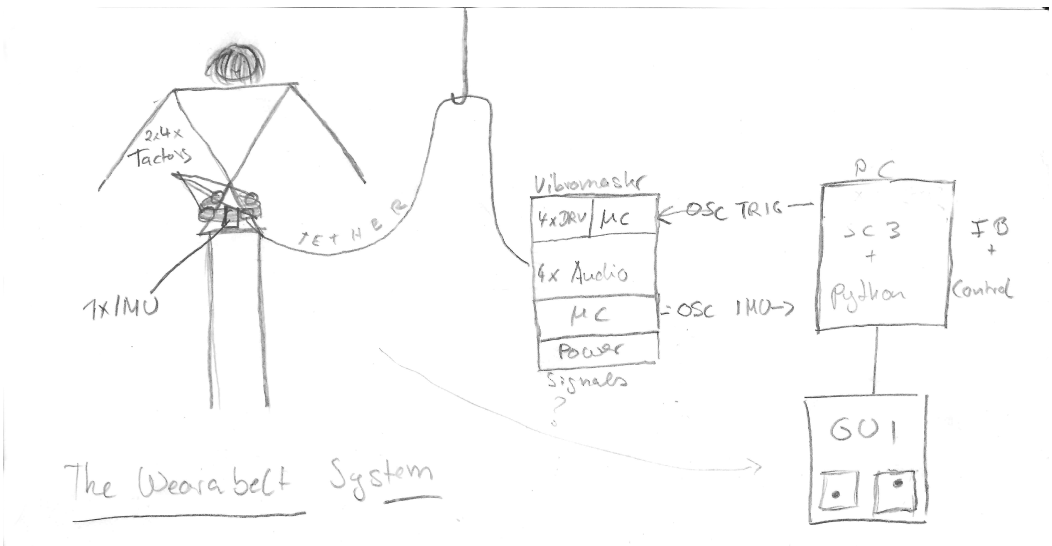


Figure 2: Belt System Overview

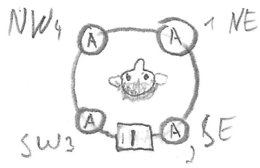


Figure 3: Tactor/Sensor Placement on Belt

## Actuator Base Measurements (4)

To be comparable, actuator power is commonly defined as accelation of a freehanging 100 gram load. In contrast, the load the actuator has to move in a real-world integration depends on the actuator integration mass and the coupling tightness. Here, we compare the characteristics of two respresentative tactors: vibration motors / Eccentric Rotating mass Motors (ERM) and the Lofelt Sound Engine voice coil. Our test setup is the VT belt, with an accelerometer attached to an actuator pod, with a "tight but comfortable" strap tightness. Acceleration values in the following are thus with regard to this setup, and not to the classical test load.

### Acceleration Measurement Apparatus

We choose a compact, wearable ADC over a potentially more precise stationary instrumentation such as an NiDAQ to be able to measure accelerations in-situ. We mounted an analog accelerometer (ADXL330) on top of the two actuators. It is sampled at 8 KHz/13 Bit through a Teensy 4.0. The combined weight of the belt actuators is around X grams (ERM+Lofelt). While the maximum acceleration is over the 3G limit of the ADXL330, this is not a practical concern as such strong vibrations over the limit for a comfortable long-term use. In practice, we limit the actuation strength to 40% for both ERMs and voice coils, or roughly 1G.

### ERM Duty Cycle vs. Acceleration

In Eccentric Rotating Mass Motors (ERMs), vibration is created by spinning an eccentric mass at varying velocities, increasing vibration amplitude along with vibration frequency. The ERMs in our feedback belt are the cylindrical type (Parallax Inc. 28822 / VZ7AL2B1692082, ø 23 mm × 8.8 mm, rated at 12,000 ± 2,500 rpm). We drive the ERMs through a TI DRV2605 driver chip per actuator. Below is the aggregated amplitude frequency response over six repetitions; three standing, three sitting, on the back left position.

The amplitude is clipped at 3G due to the sensor's limitations. The 40% duty cycle maximum leads to a vibration at around 91 Hz and 2G acceleration.

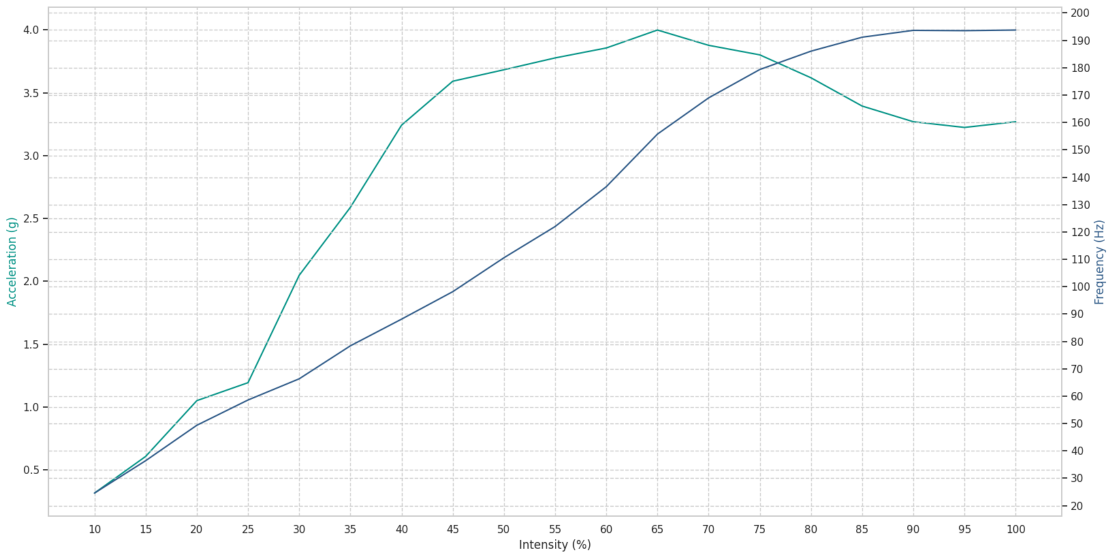


Figure 4: ERM Frequency/Amplitude Response, In Belt

### Inter-Actuator-Coupling

Front Left actuated / Back Left / Front Right measured

### Lofelt Frequency Response in Belt

The Lofelt Sound engine tactor, embedded in the belt exhibits a clear resonance peak at 63 Hertz. Shown is the axis in line with the actuator's voice coil spring.

This is different for the ERM type actuator.

An earlier measurement in a free-hanging setup exhibits a second peak at a lower frequency; and also illustrates how the two axes in the plane of the belt vibrate almost closely at the main resonance point, while the third axis, perpendicular to the belts surface, does not vibrate much.

### Pulse Sharpness Comparison

At different amplitudes/frequencies (need critical path here!)

## Stimulus Definition

- Build the game so I can play it everyday, and test on myself
- Bring back the NanoKontrol interface and play around with min/max/etc parameters on myself.

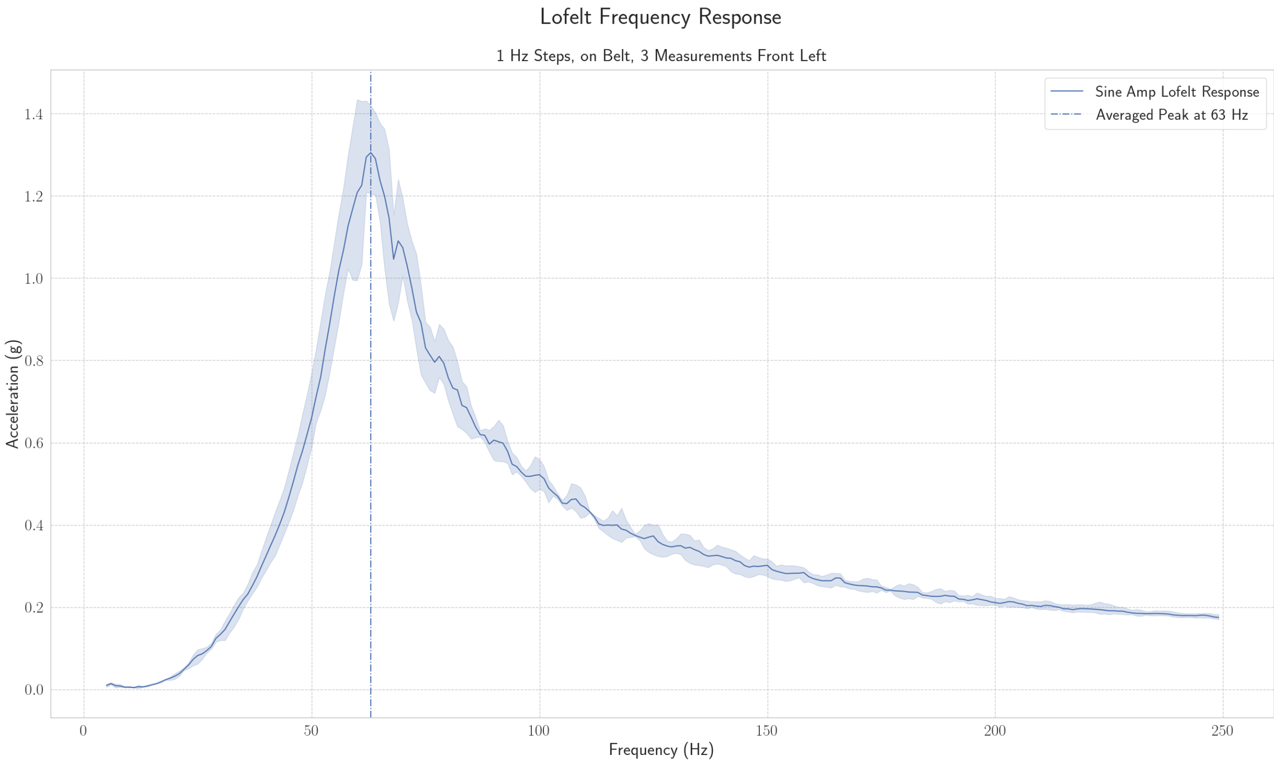


Figure 5: Lofelt Frequency Respone, In Belt

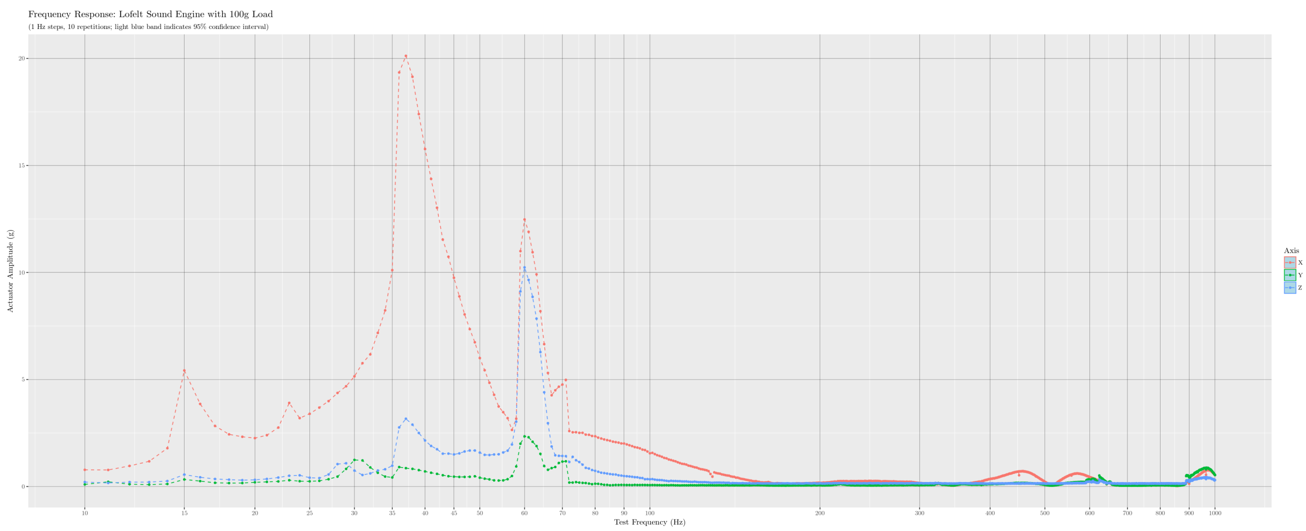


Figure 6: Lofelt Frequency Respone, Free Hanging

#### Perceptual Dimensions (2)

- Stimulus Dimensions

#### Discussion (1)

### Study

- Explain the apparatus, the research questions, and the measurement procedure
- Allow individuals to adjust parameters? Need to adjust amplitude per-user anyway

#### Description (2)

### Analysis and Discussion (4)

- Summarize the data and analyze it towards the research questions
- Discuss the findings and put them into context
- Outline future work

### Conclusion (2)

## Plan (outdated, ignore)

### Major Practical Steps

- revive & sync this doc
- Baseline Measurements both actuators, pulsing; quantitative analysis
- Literature revisit; structure RW; write out the stuff from the spreadsheet
- Define Research Questions
- Bug fixing in XP software; features
- Pilot Study, Analysis
- Adapt, Recruit + Execute for Main Study
- Analyze + Discuss

### Timeline

| When | Wat |
|---|---|
| 17.07. | Outline refresh, fresh data |
| 24.07. | More base measurements |
| 31.07. | FB Stimulus brainstorm |
| 07.08. | Pilot Study Fix + Setup |
| 14.08. | Pilot Study |
| 21.08. | " Data Analysis |
| 28.08. | "Bux fixed, Recruit" |
| 04.09. | Study Execute |
| 11.09. | " |
| 18.09. | Data Recorded, Analysis |
| 25.09. | Analysis |
| 02.10. | Writeup |
| 09.10. | Buffer |
| 15.10. | Study in the box |

### Skills Needed

- MTL crew advice for RQ
- Stats advice