Design of a Wrist-Worn Haptic Device for Human Motion Guidance

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Abstract

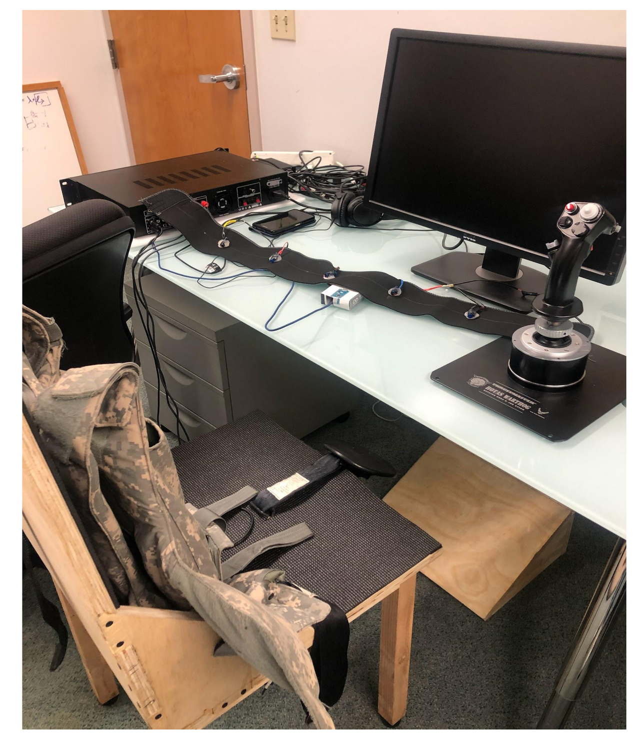
Vibrations play an important role in our everyday lives. From alerting us about incoming text messages to immersing us into virtual worlds, vibrations can be leveraged to relay a great amount of information through a mechanism much more subtle than ones typically used by electronic devices and media. Though powerful communication channels, most vibration devices are limited in the amount of information they can convey, typically by their size, practicality, and the amount of vibration actuators they are able to house.

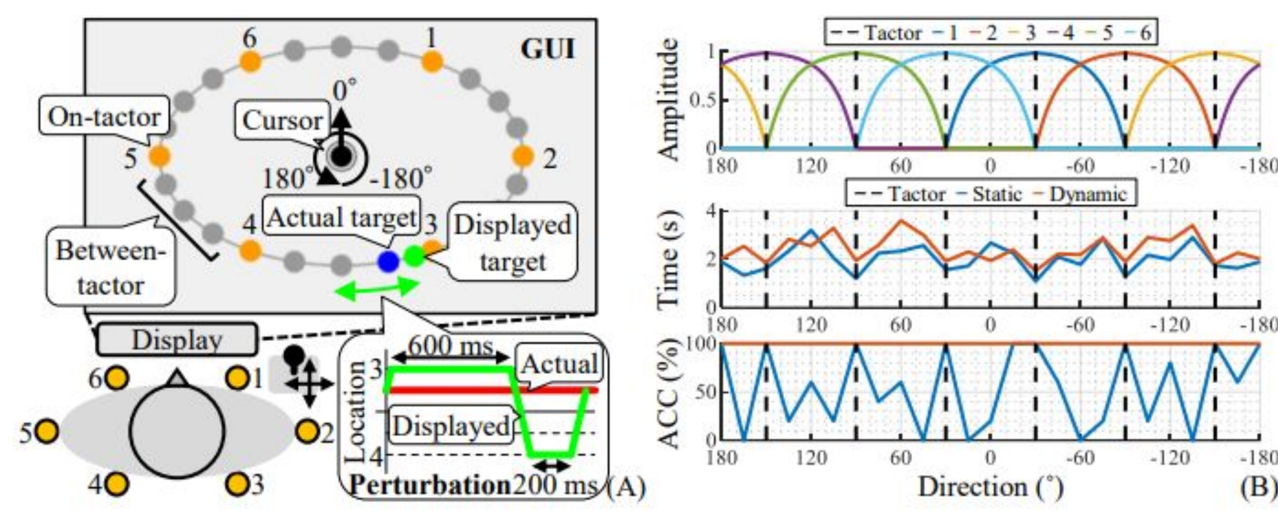
This projects aims to design a fully-portable wrist-worn haptic device that will utilize multiple vibrotactile motors to communicate complex information to the user derived from their real-time motion. Due to the varying concentration of mechanoreceptors across different regions of the human body and the early stages of the study, this device will prioritize modularity and flexibility as well as safety and robustness to ensure successful applications in further user studies.

Background

Between-Tactor Display Using Dynamic Tactile Stimuli

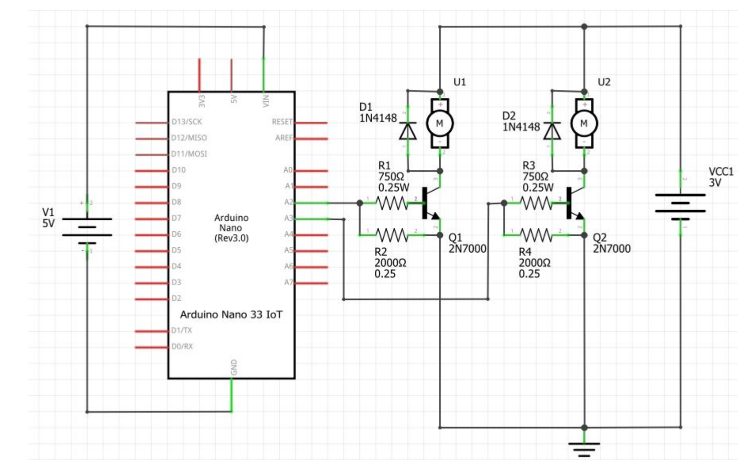
Using dynamic tactile stimuli, the number of vibrotactile motors present in a distributed tactile display can be reduced significantly while maintaining high resolution. This method can be used to create multiple illusory vibration locations between the motors and thus allow for greater information relay to the user. [1]

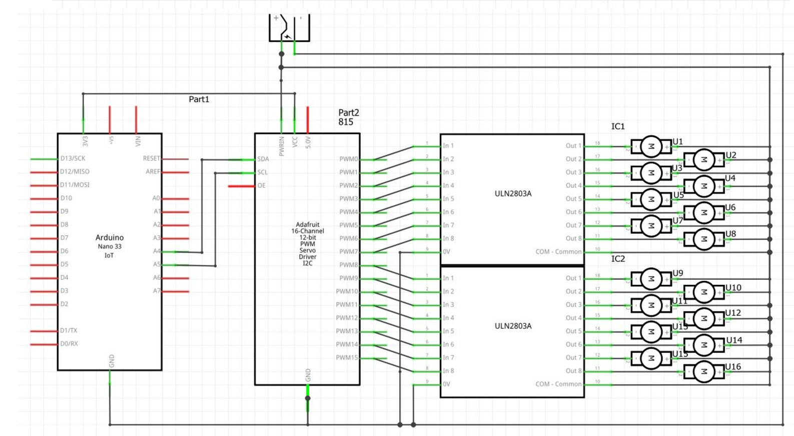


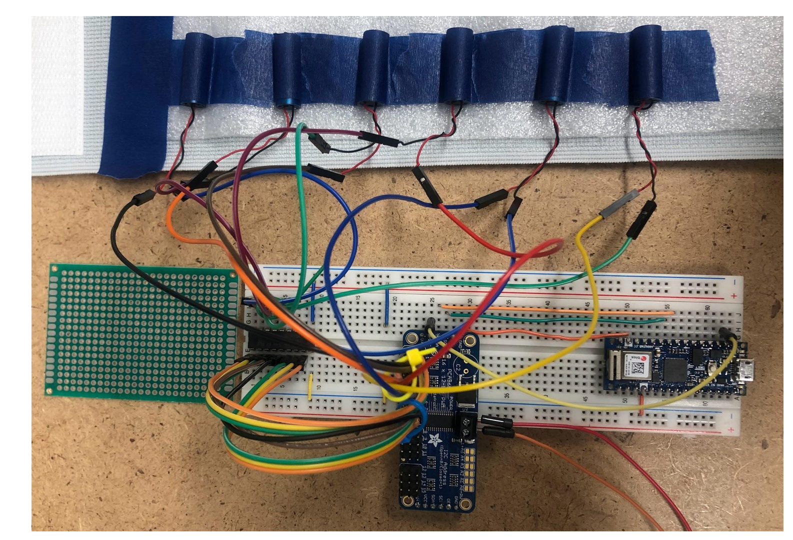


$$y(x) = \begin{cases} \max\left(1 - \exp\left(-\frac{x-d+60^\circ}{T}\right), 0\right) & x \le d \\ \max\left(1 - \exp\left(-\frac{d-x+60^\circ}{T}\right), 0\right) & x > d \end{cases}$$

Methods for Circuit Design







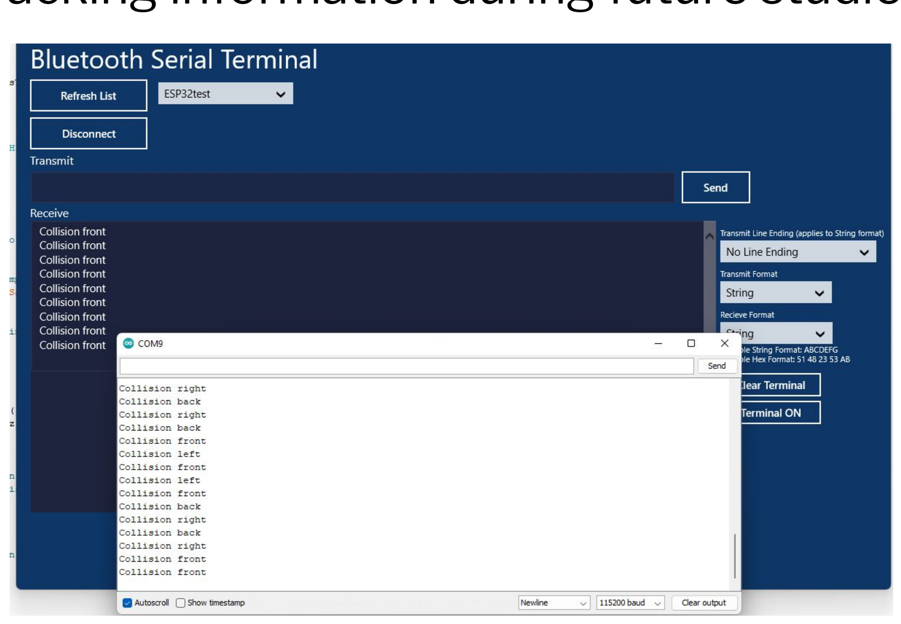
An Arduino Nano 33 IoT was chosen as the central controller for the wearable device due to its inclusion of an IMU, Bluetooth capabilities, and small size. PWM control of the motors generated varied vibrations essential to creating a functional haptic illusory display. Although the Arduino Nano 33 IoT is capable of directly controlling the motors through a decoupled transistor circuit, the physical size of this system as well as the CPU usage of the Arduino made this design impractical. Instead, a PCA9685 chip mounted on an LED driver board was repurposed to drive up to 16 motors through PWM with only two pins from the Arduino (through I2C communication).

By incorporating transistor arrays, this design minimized the computational load of the Arduino, reduced its physical size, and increased the robustness of the circuit. The vibrotactile motors were selected by measuring that their vibration force was strong enough to be felt on wrist skin.

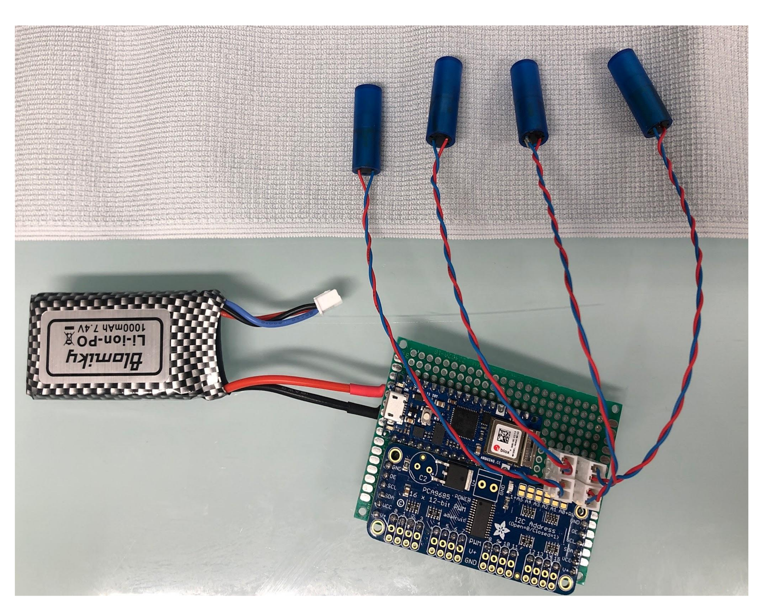
Classic BT Communication

The Arduino Nano 33 IoT is programed to work with Bluetooth Low Energy. Although BLE is power efficient and commonly used in wearables, its relatively low speed is not ideal for the real time haptic feedback that the device needs to output to the user.

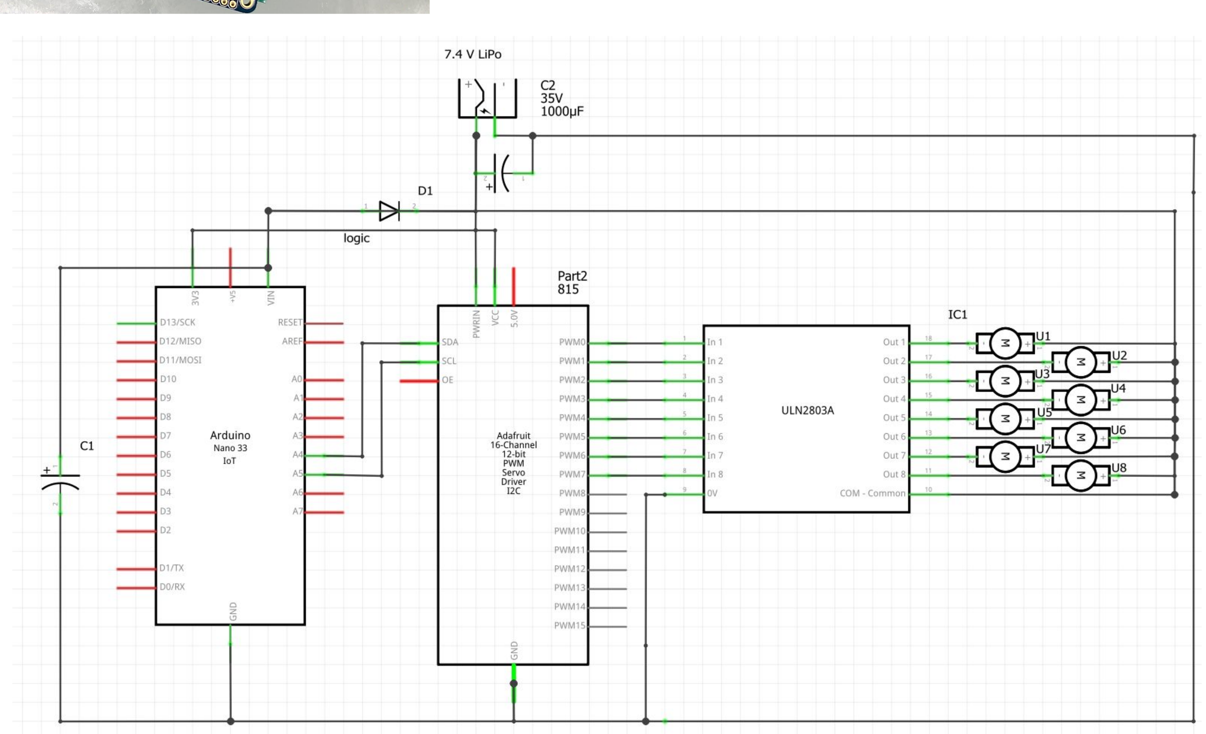
However, the ESP32 chip in the Arduino can support Classic Bluetooth after flashing the chip's firmware and modifying its default CPU frequency, partition schemes, and flash values until a stable connection and baud rate can be established. This connection allows for faster communication, which creates opportunities to run more complex algorithms remotely as well as record better tracking information during future studies.



Results



The current iteration of the device has been stress tested for robustness and reduced to using a single Lipo battery as a power source. Decoupling capacitors and diodes have been added to regulate noise from the motors and prevent malfunction of the controllers.



Next Steps

With the circuit now complete and tested for robustness as well as configured for high speed data transmission, next steps would include finalizing a custom PCB prototype and proceeding with motor control algorithm development and user testing. Like the aforementioned research, the number of motors and the dynamic activation of motor pairs can be tested to compare the results between different regions of the body, such as the wrist and torso. Furthermore, the device can be used to monitor the effect of haptic feedback on walking patterns, motion guidance, and more.

Acknowledgments

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References

[1] Ryo Eguchi, David Vacek, Cole Godzinski, Silvia Curry, Max Evans, Allison M. Okamura, "Between-Tactor Display Using Dynamic Tactile Stimuli" EuroHaptics 2022. arXiv:2207.07120 [cs.HC]