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SpatialSense: Wireless Haptic Feedback System for the Visually Impaired

Daniel Gorbunov, DARoS Lab, 2023

ETH Zurich CYBATHLON

Vision Assistance Race (VIS) Objectives:

- Walk while keeping tray upright
  - Don’t spill soup contents
  - Place tray in right location
- Fill cup to specific height
  - Don’t spill cup contents
  - Place cup in correct location

→ Reliable hardware!

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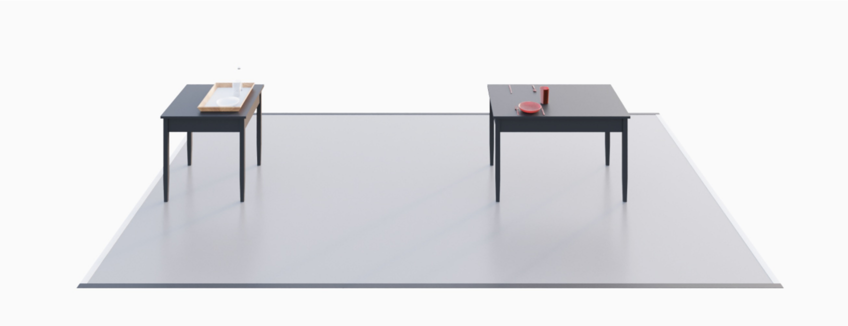
ETH zürich



Design Considerations

- Wireless haptic feedback system
- Single-board microcontroller
  - All features and ICs integrated
- High QoS
  - Very reliable
  - No potential connection/pairing issues
  - No packet loss
- Ultra low-latency
  - Ideally < 40ms response time
- Battery powered
  - > 2hr battery life

Spatial Sense

Design Process

- Time Constraint: < 2 months
  - Prototype
  - Schematic & PCB Layout
  - Production & Shipping
  - Assembly
  - Software & Testing

→ **Must get it right the first time**

→ **No room for error**

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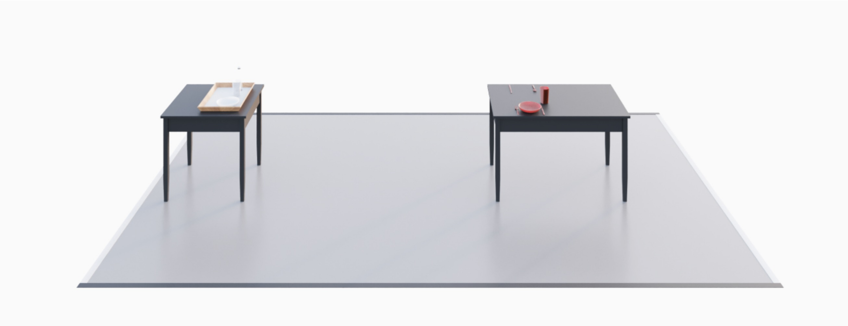

9 Different Modules

- Ideal solution → One board for everything
  - Easy assembly
  - Code duplication
  - Some boards will have different components

DEVICE:	HOST_ADDR:	RX:	TX:	DESC:
Vibr0	0	Yes		Vibration Motor 0
Vibr1	1	Yes		Vibration Motor 1
Vibr2	2	Yes		Vibration Motor 2
Vibr3	3	Yes		Vibration Motor 3
IMU	4		Yes	IMU
Scale	5		Yes	Scale Load Cell
ButtonSender	6		Yes	Button Module
ButtonReceiver	7	Yes		Button Signal Receiver
VisionSender	8		Yes	Vision Mode Transmitter

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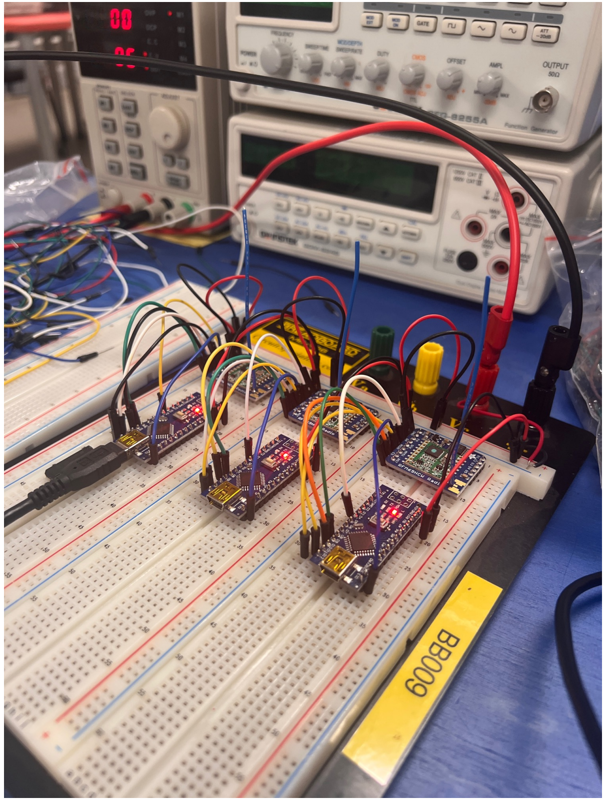
Prototype

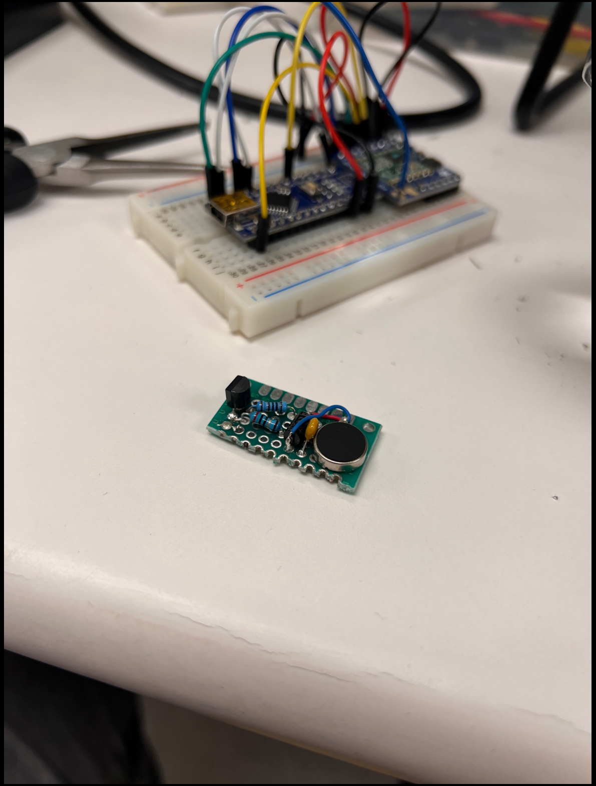
- Breadboard-based vibration modules (x5)

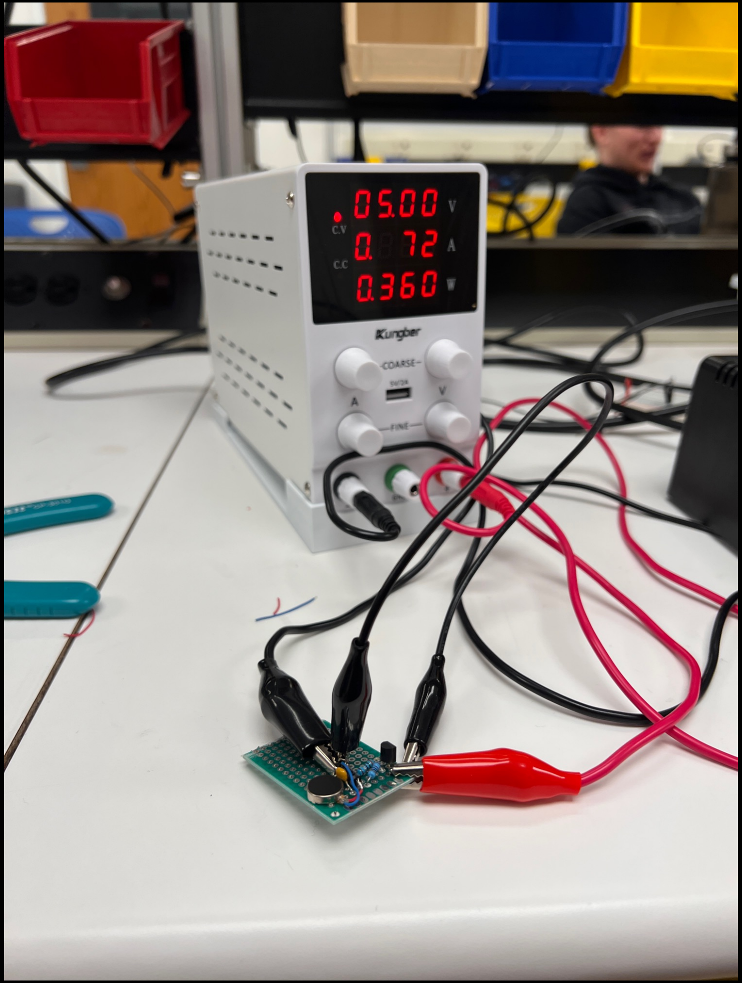
<u>Components:</u>

- Arduino Nano
- RFM69HCW Packet Radio
- Custom ERM FET Driver
- MPU6050 IMU
- 9V Battery
- 3D Printed Cases



Custom MOSFET Driver





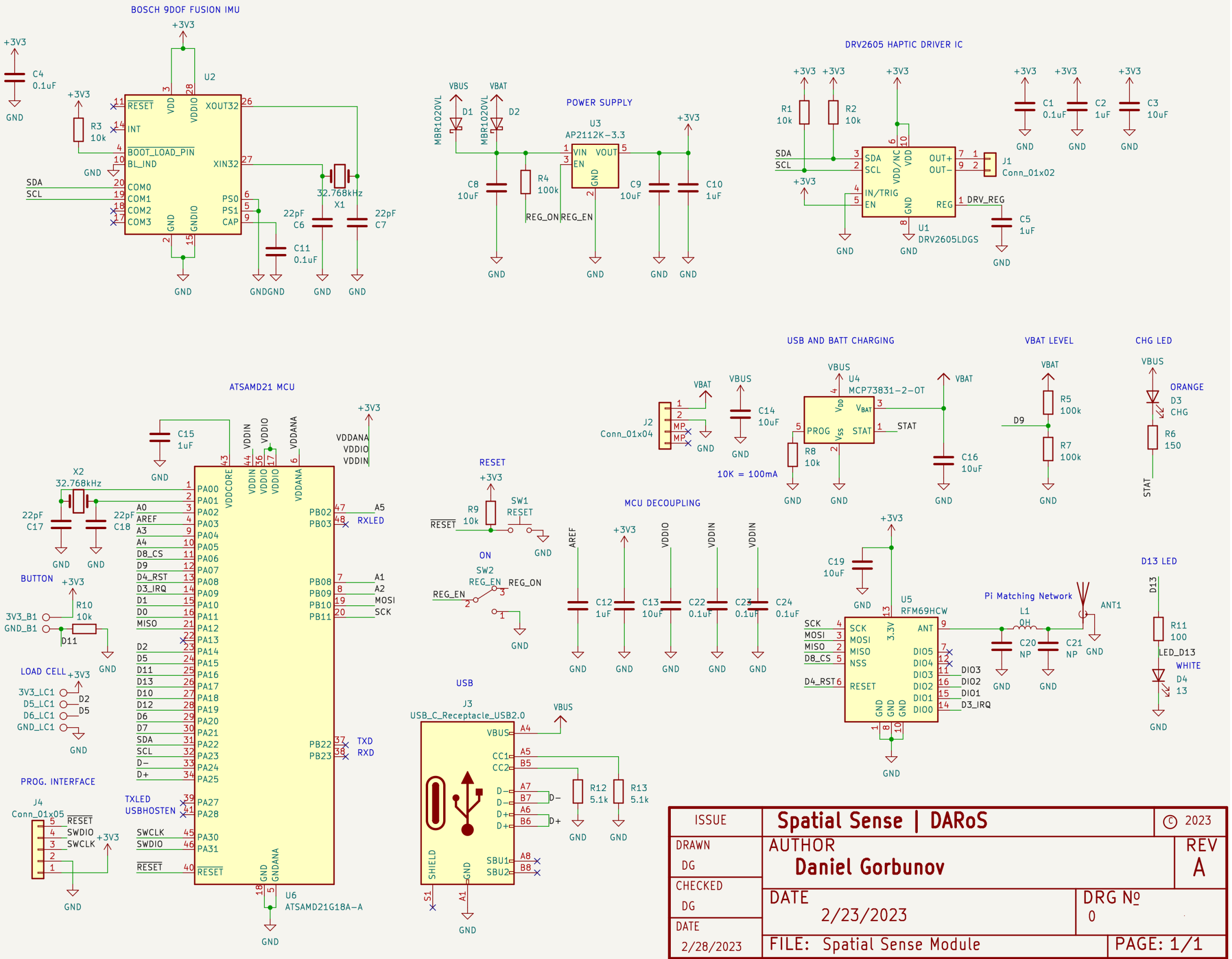
Prototype: Breadboards

→ Big, heavy, too many wires

→ Need something custom

Solution: Custom PCB!

Schematic


BOSCH 9DOF FUSION IMU
POWER SUPPLY
DRV2605 HAPTIC DRIVER IC
ATSAMD21 MCU
USB AND BATT CHARGING
VBAT LEVEL
CHG LED
RESET
ON
MCU DECOUPLING
Pi Matching Network
D13 LED
BUTTON
LOAD CELL
PROG. INTERFACE
USB
10K = 100mA
U2
U3 AP2112K-3.3
U1 DRV2605LDGS
U4 MCP73831-2-OT
U5 RFM69HCW
U6 ATSAMD21G18A-A
J3 USB_C_Receptacle_USB2.0
ISSUE
Spatial Sense | DARoS
© 2023
DRAWN
DG
AUTHOR
Daniel Gorbunov
REV
A
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2/23/2023
DRG №
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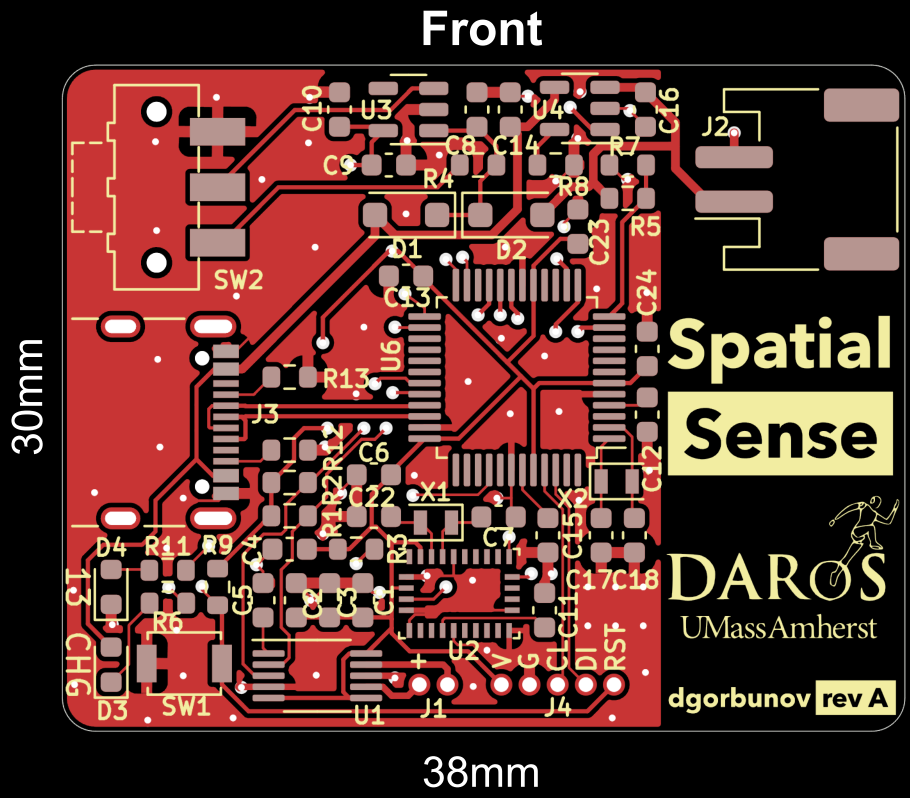
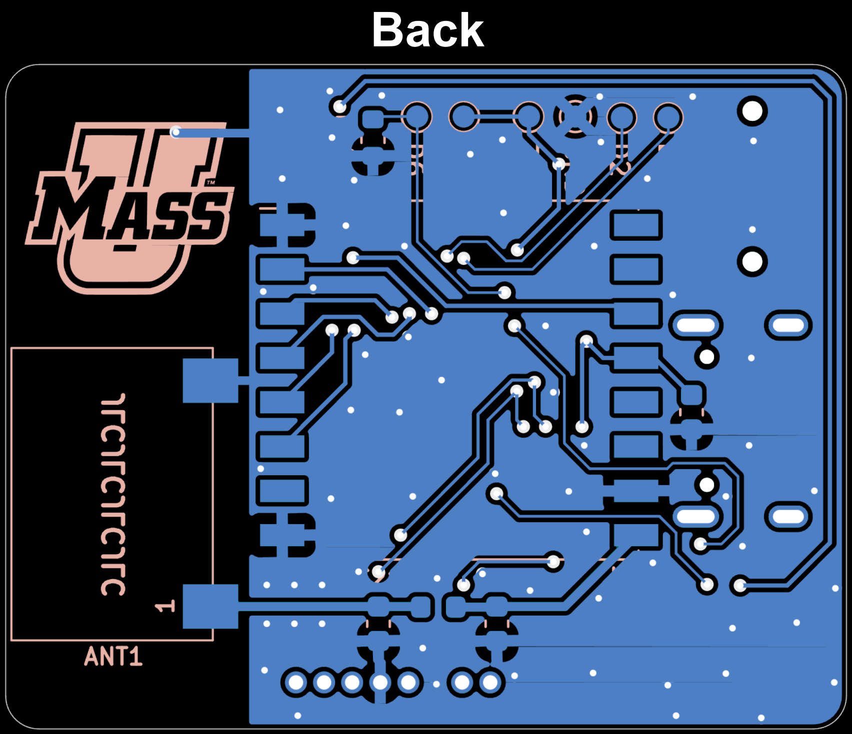
DATE
2/28/2023
FILE: Spatial Sense Module
PAGE: 1/1

PCB Layout


Front
Spatial
Sense
DAROS
UMass Amherst
dgorbunov rev A
30mm
38mm


Back
ANT1

Spatial Sense

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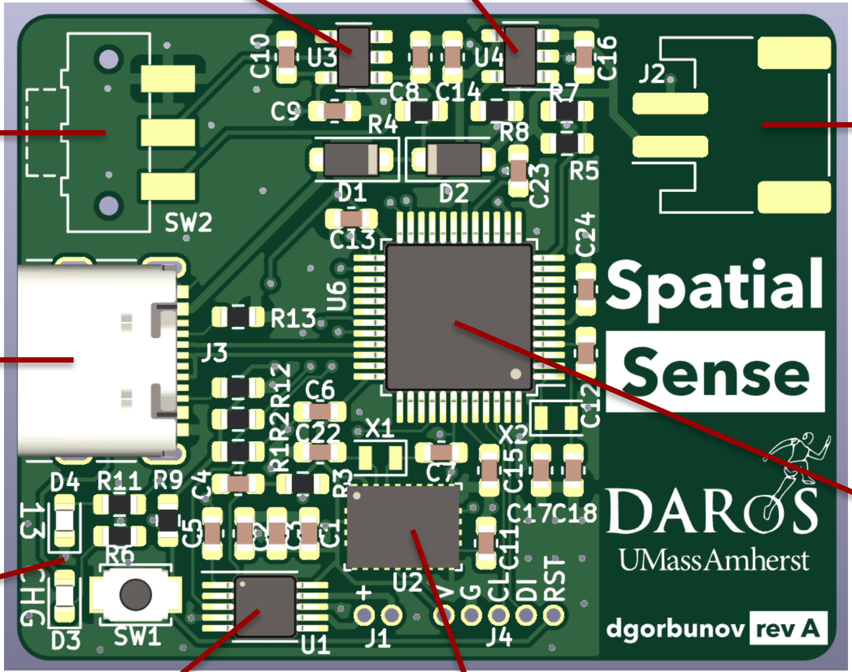
Power Supply

Batt. Charging

Power Switch

LiPo Battery Connector

USB-C Receptacle



Indicator LEDs

Atmel ATSAMD21
ARM Microcontroller

TI DRV2605L
Haptic Motor Driver

Bosch BNO085
9DoF IMU+MCU

Spatial Sense

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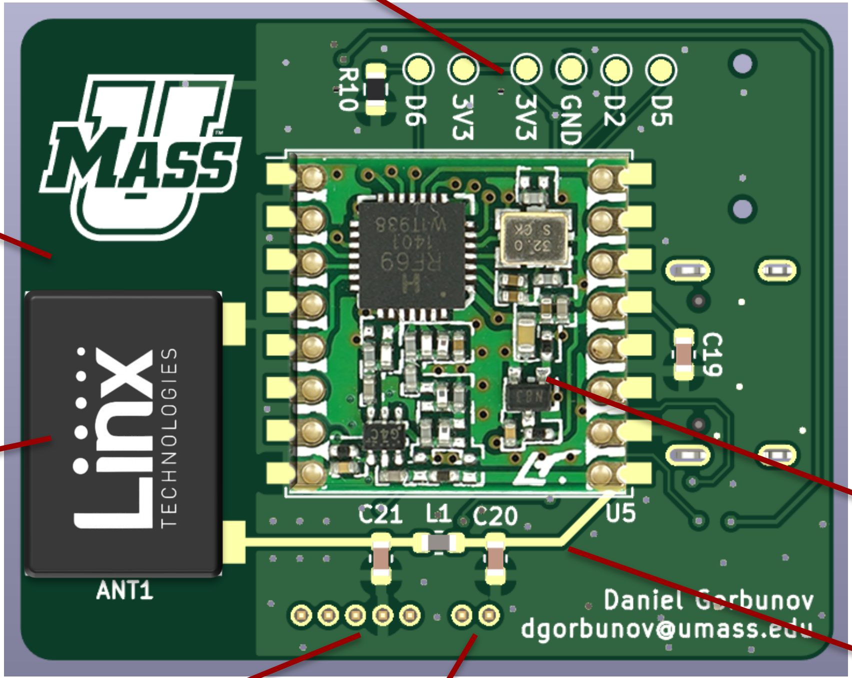
Breakouts (extra features)

RF Plane (no GND)

Linx Antenna
915MHz, Tuned
50Ω Impedance



RFM69HCW
915MHz Packet Radio Transceiver

RF Microstrip + Impedance Matching Network

SWD Programming Interface

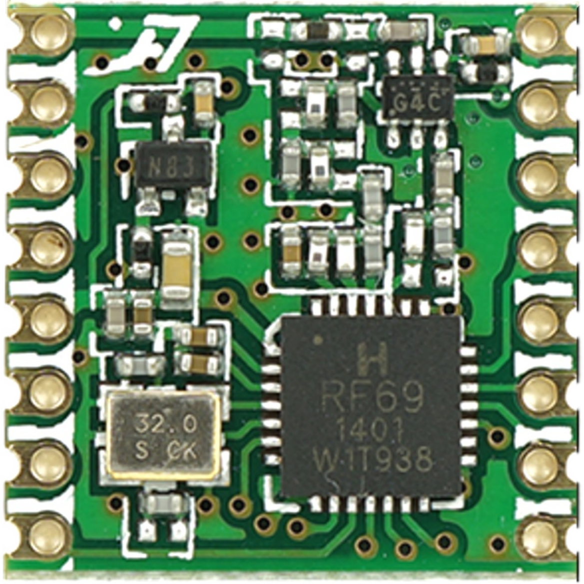
Vibration Motor Pins

Why Radio?

WiFi and BLE were considered, but…

Packet Radio was chosen for:

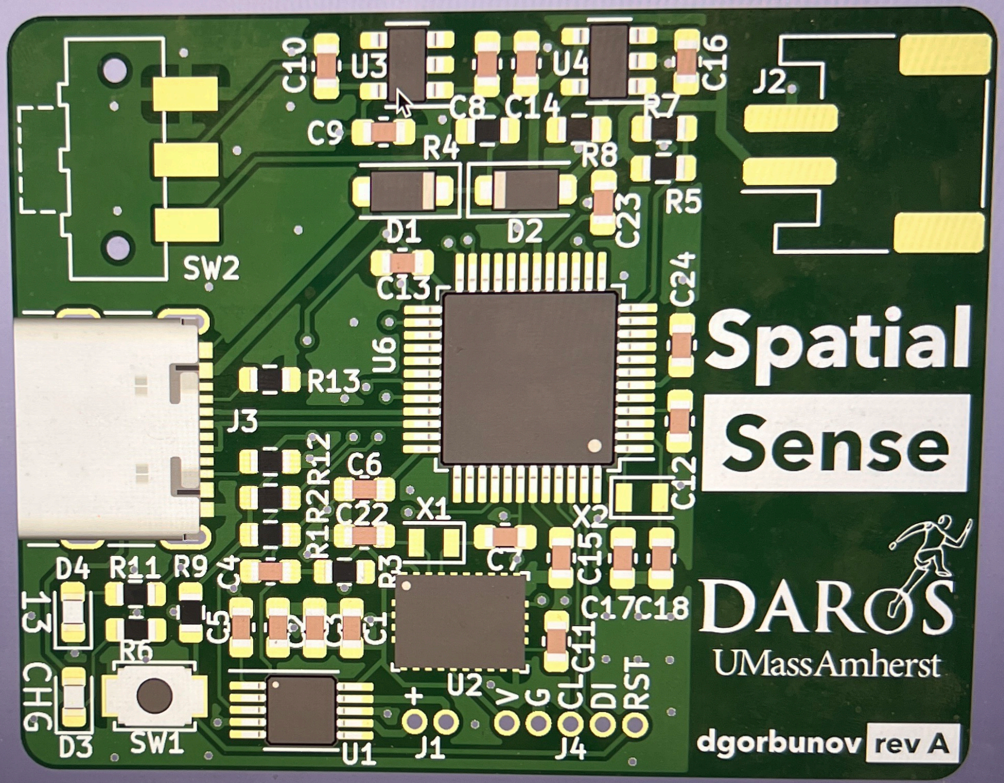
- Low Latency
  - *3-5ms latency end-to-end*
- High QoS
  - *No pairing process, reliable connection*
- High data rate not needed
  - *Packets are < 66 bytes each, max. 300kbps*
- Easy mesh network
  - *256 networks x 256 nodes*
- AES-128 encryption + ACKs



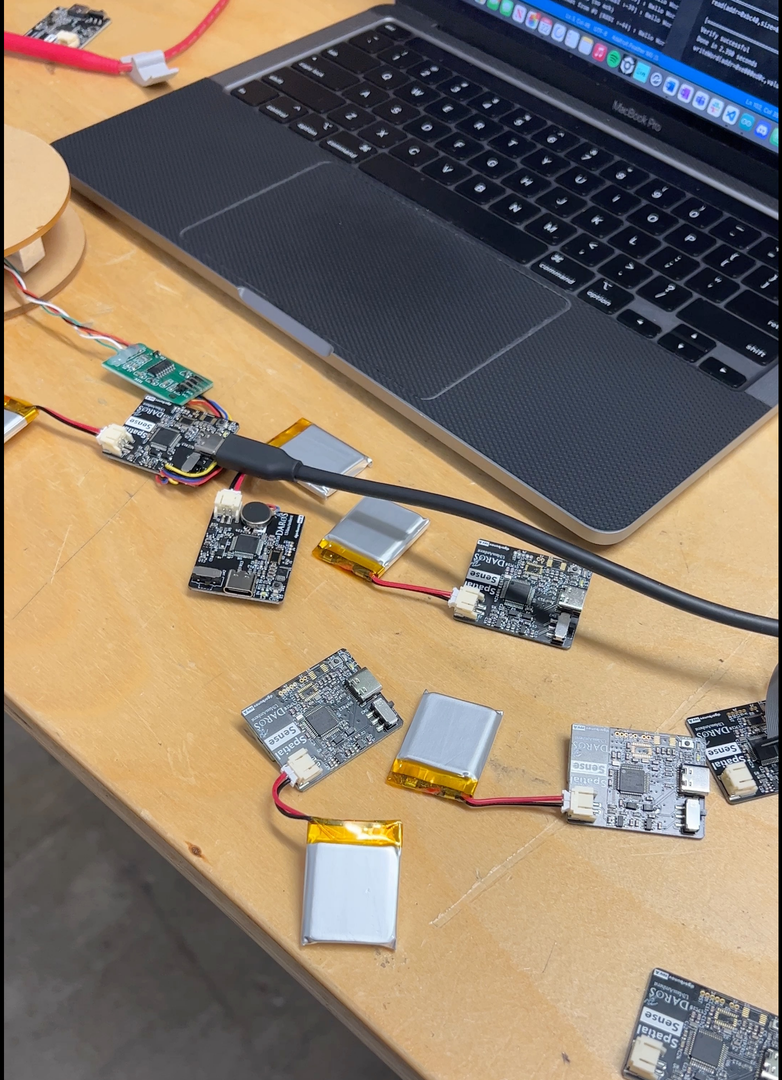
RFM69HCW
915MHz Packet Radio Transceiver
SPI, 0.5-5km range, +20dBm @100mW

Results

(it's small!)

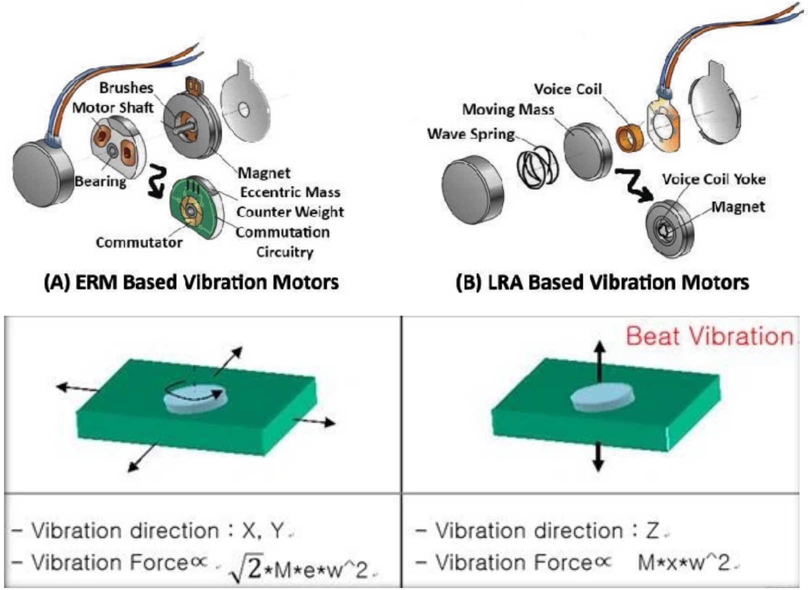


Wireless Comm. Test



ERM vs. LRA for Haptics

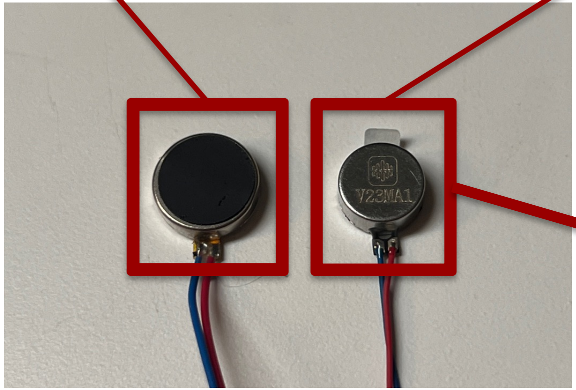
- We observed weak ERM vibration and poor transient response
- ERM is slow to accelerate
- Has high power consumption
- Vibrates in wrong directions
  - Z-axis is preferred for wearable haptics

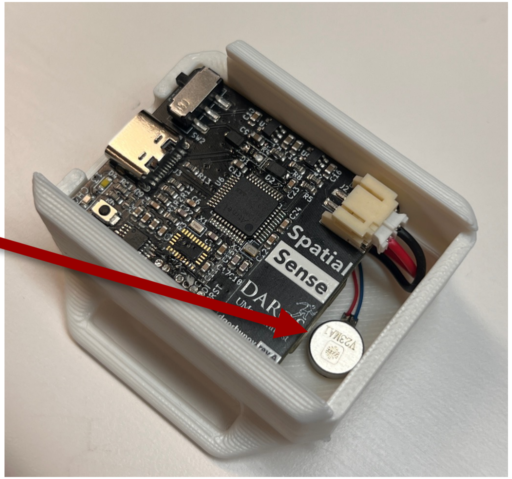


→ Switched from ERM to LRA

ERM vs. LRA for Haptics

Generic ERM   Brand-name LRA Vybronics

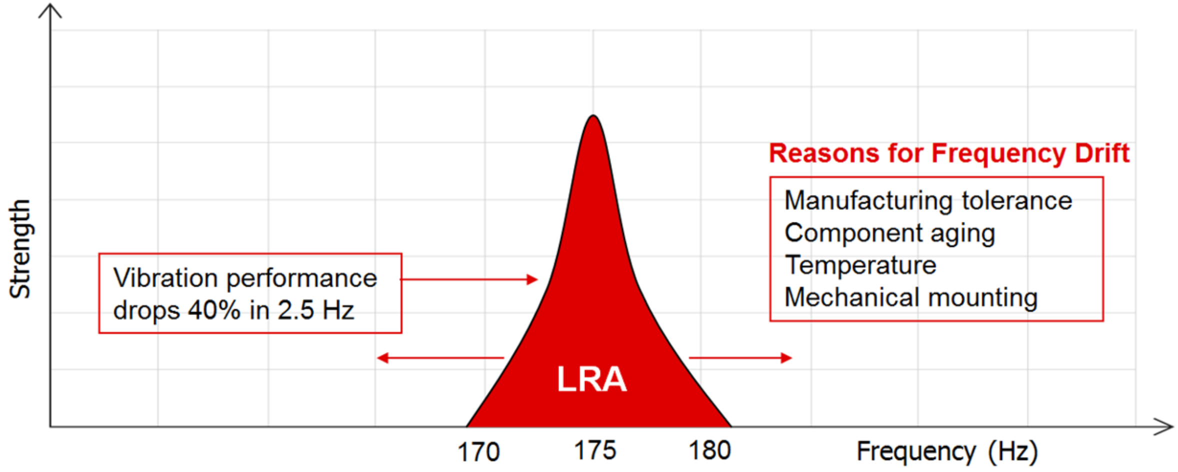




- → **Much stronger vibration**
- → **Fast acceleration, sharp transients**

About LRAs

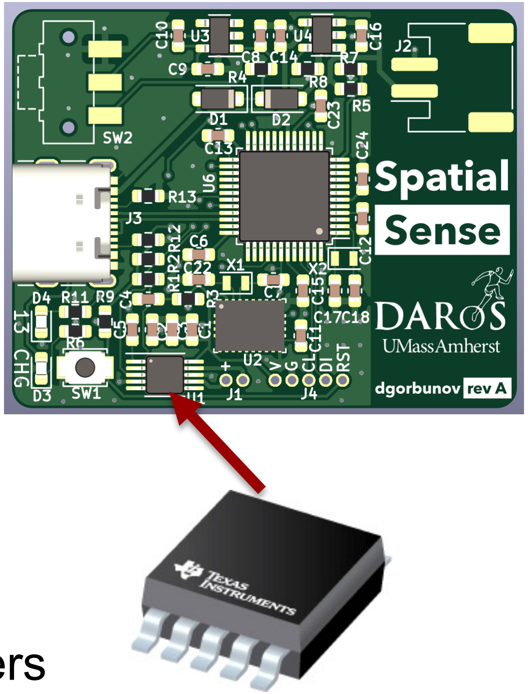
- ERMs use DC…
- LRAs are tuned to a resonant frequency (in our case 235Hz) and require AC at that frequency



TI DRV2605L LRA Driver

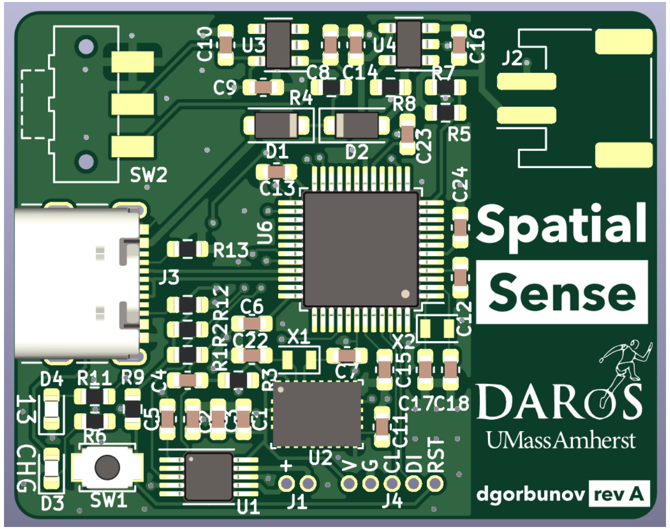
- Industry standard, i2C controlled
- Auto-resonance tracking
  - LRA resonance can dynamically change based on environment
  - Chip continuously samples back EMF from LRA
- Automatic closed-loop controller
  - Need to write tuning params to driver registers:
  - Drive + Overdrive Voltage
  - Braking Factor
  - Loop Gain
  - …etc

→ Spent many hours tuning control loop parameters



Other Applications

- Compact microcontroller with integrated battery, packet radio and MCU
- Integrated high-precision Bosch IMU
- Low-latency mobile sensor networks for live tracking (ex: motion tracking)
- Easily configurable for other hardware (we used external load cells and buttons)
- Large 60,000+ node networks
- Up to 5km range for remote operation

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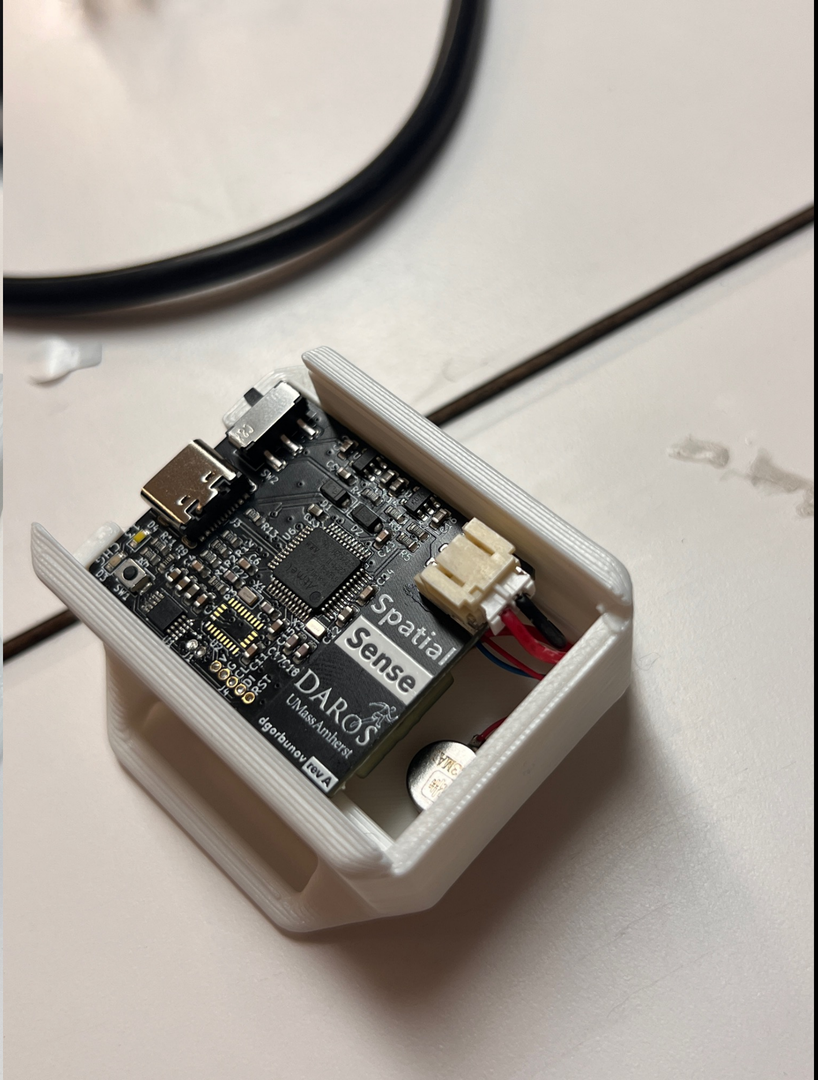
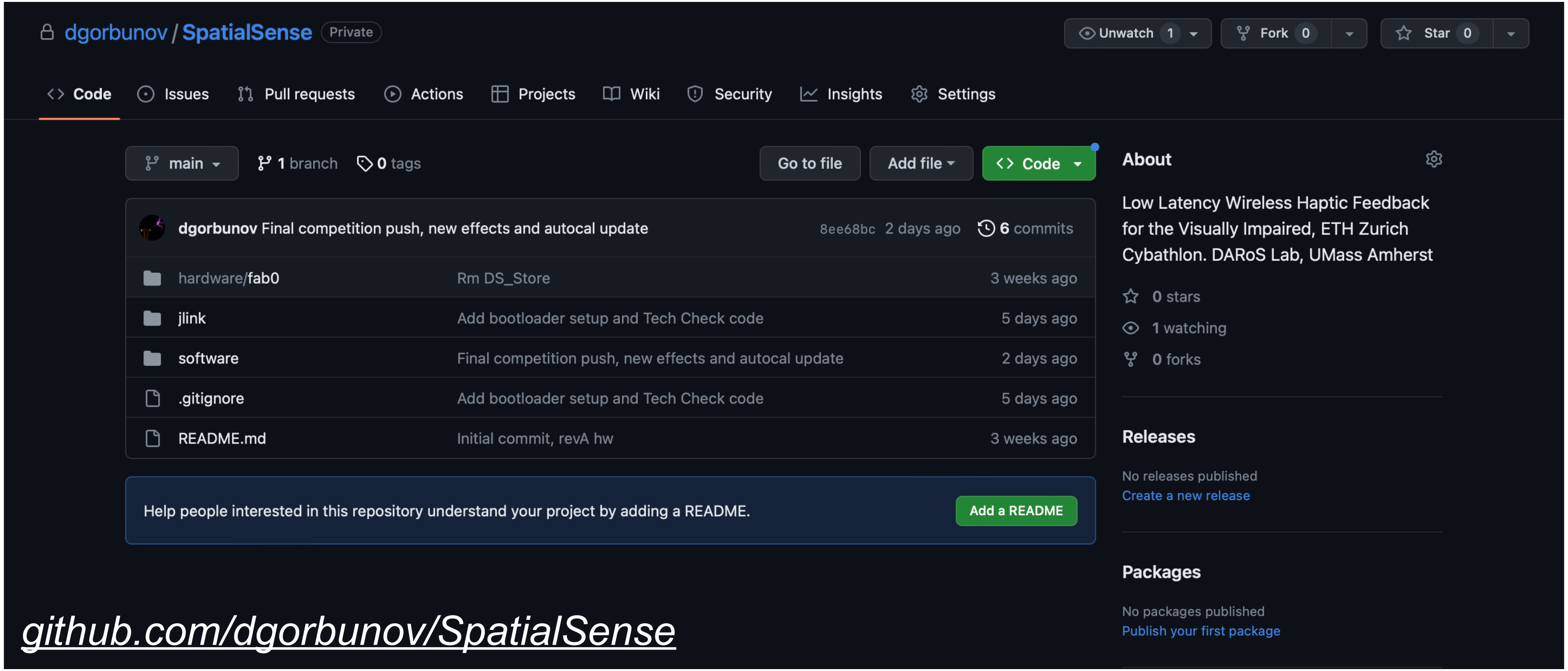

Spatial
Sense
DAROS
UMassAmherst
dgorbunov
rev A

Available on GitHub



github.com/dgorbunov/SpatialSense

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