COLLEGE OF ENGINEERING
ELECTRICAL & COMPUTER ENGINEERING
UNIVERSITY OF MICHIGAN

FloHR: Human Heart Rate Detection at a Distance using Indirect Structural Vibration Sensing

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ECE[1] [2] CISCO[3]

Ubiquitous Heart Rate for Human Health

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  - Widespread use drives a $32.7 billion USD industry in monitoring devices

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  - Widespread use drives a $32.7 billion USD industry in monitoring devices
- Ubiquitous monitoring is important:
  - Resting heart rate indicates overall health and potential for cardiovascular disease
  - Abnormal variations in heart rate are an early warning sign for illness or injury

How to monitor Heart Rate?

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Manual Measurement
Ubiquitous
Sporadic, Imprecise

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Wearable Devices
Continuous
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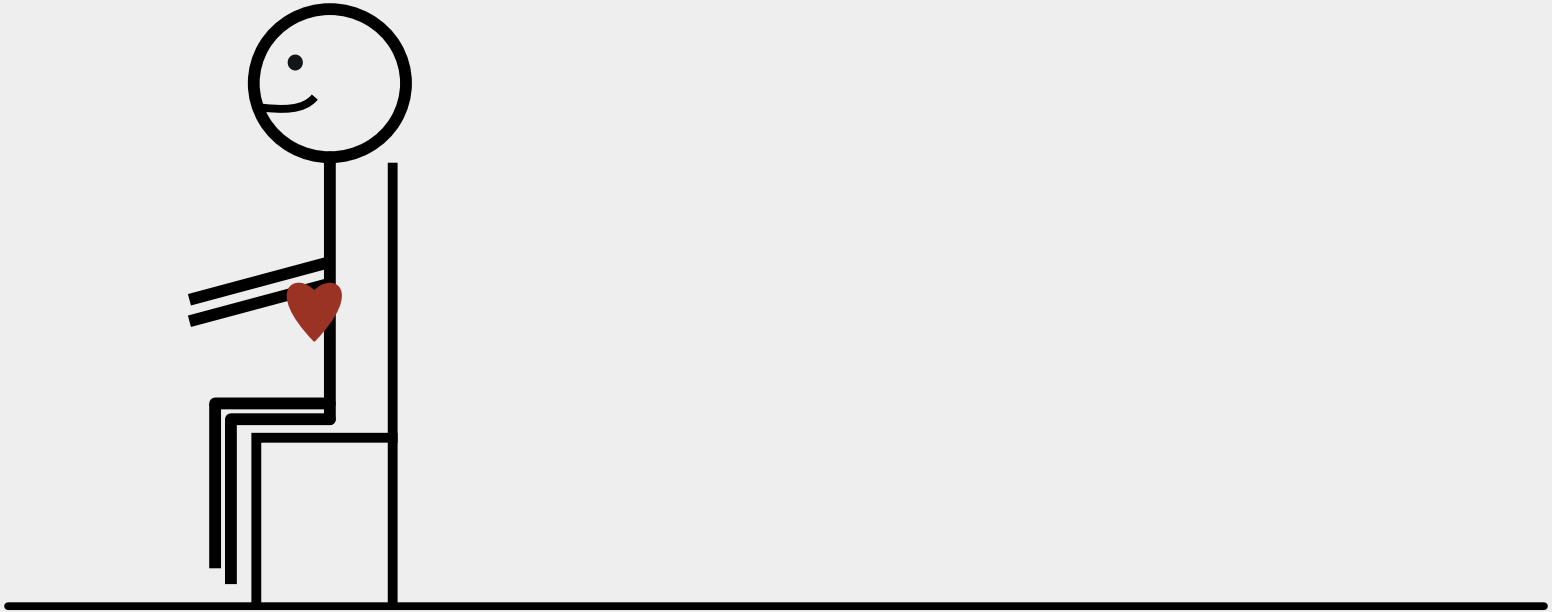
Ambient Radio and Vision
Continuous
Privacy, Line-of-Sight

Heartbeats Create Vibrations!



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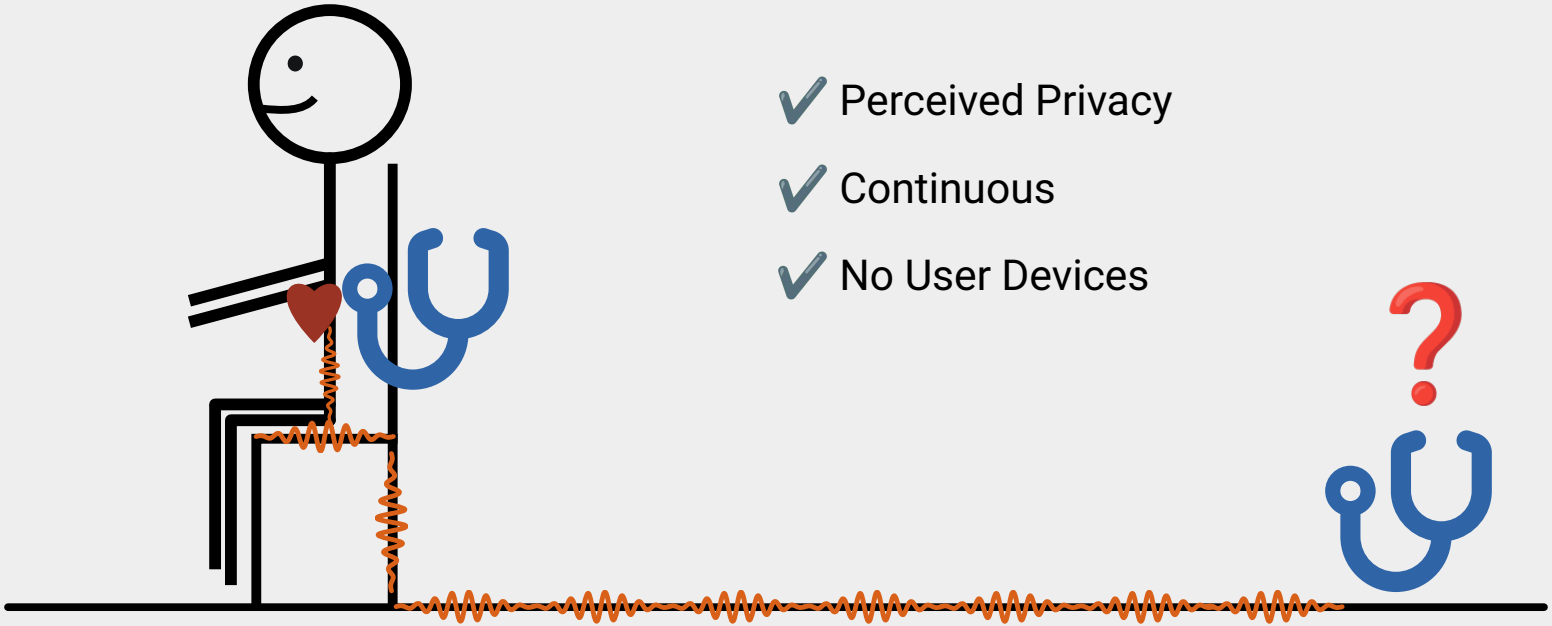
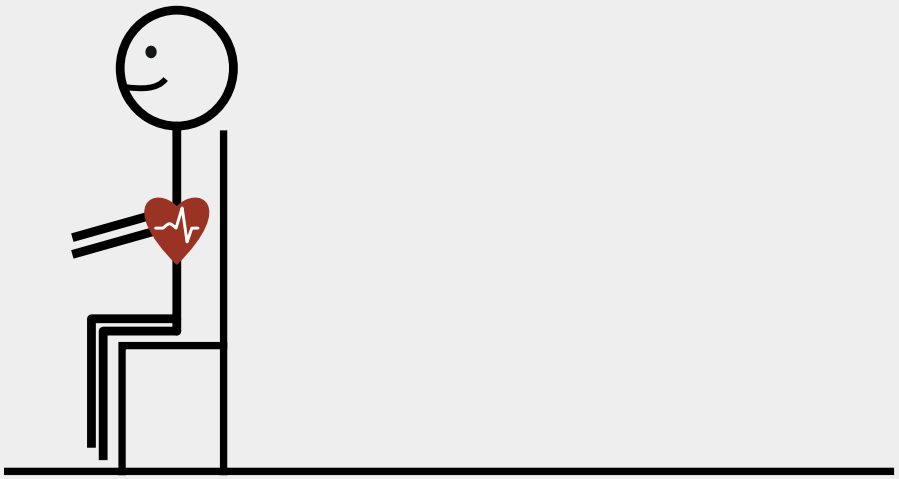
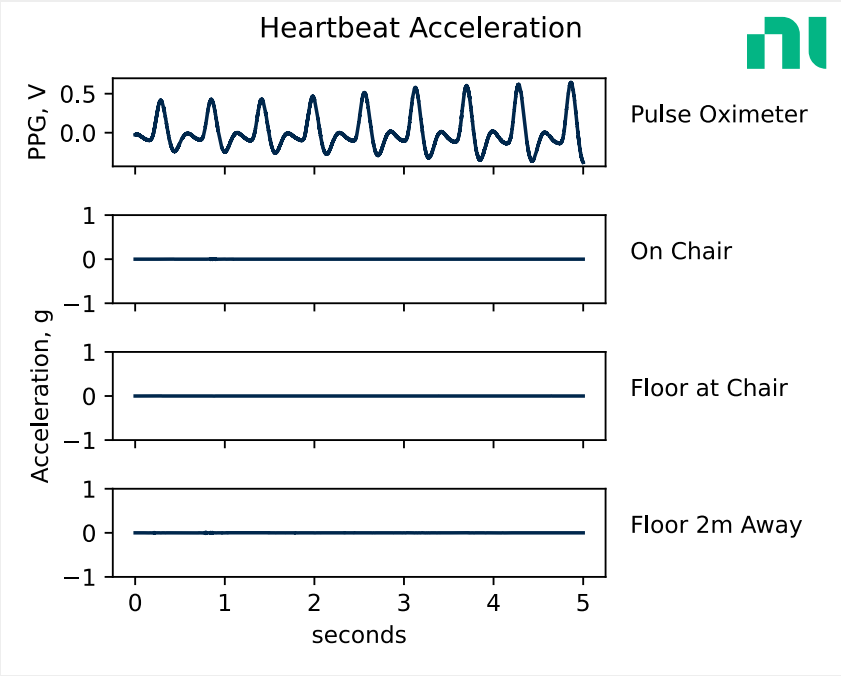


- ✔️ Perceived Privacy
- ✔️ Continuous
- ✔️ No User Devices

Are there Heartbeat-Induced Vibrations on the Floor?





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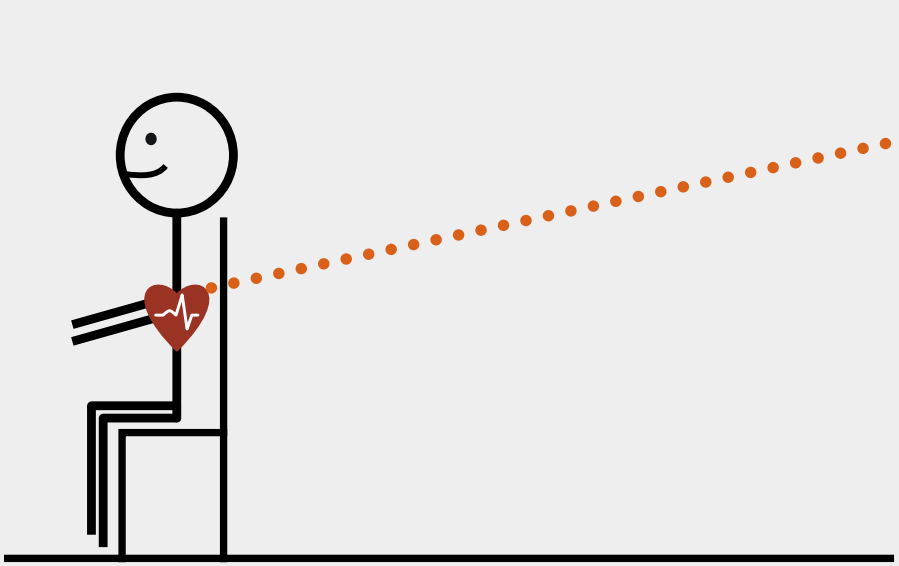

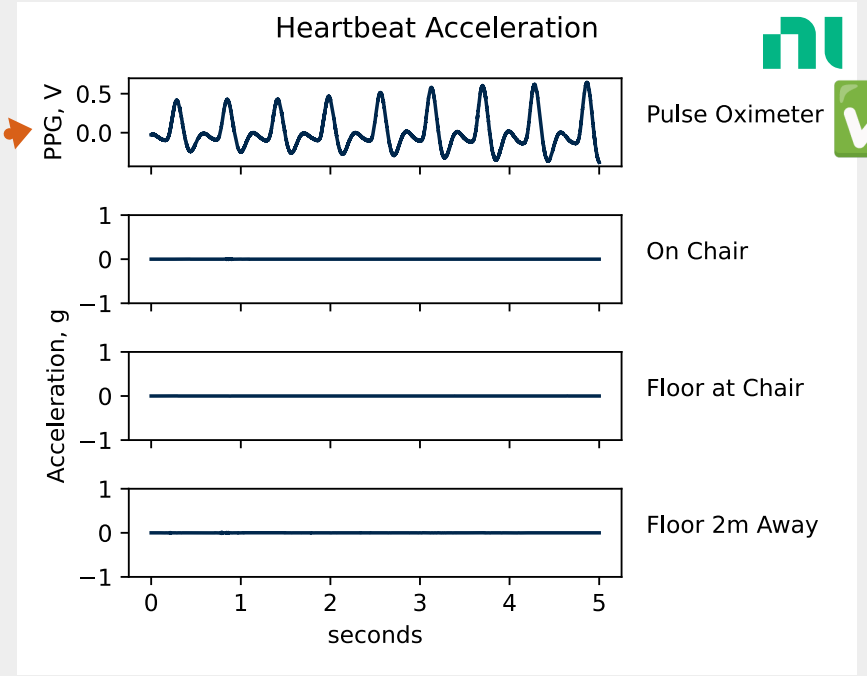

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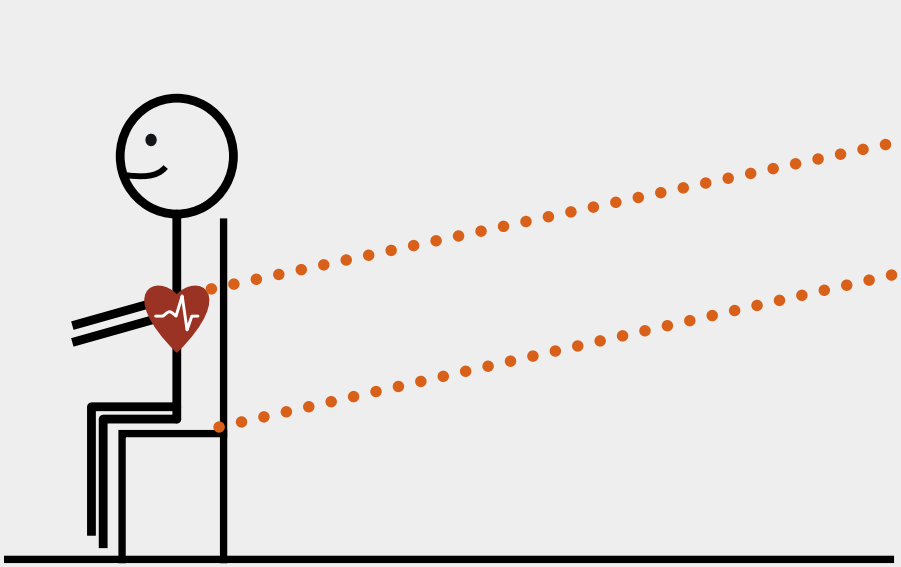

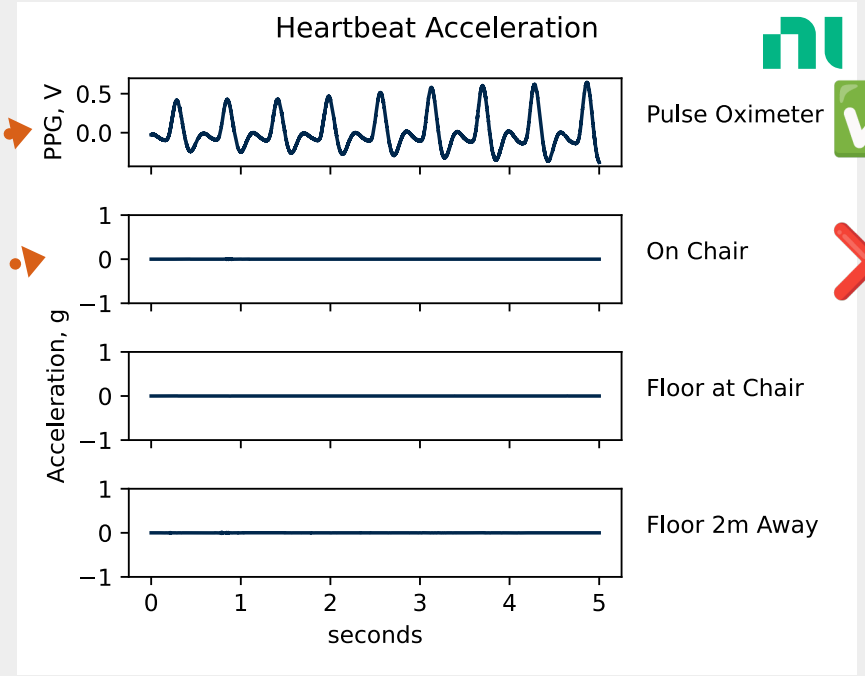

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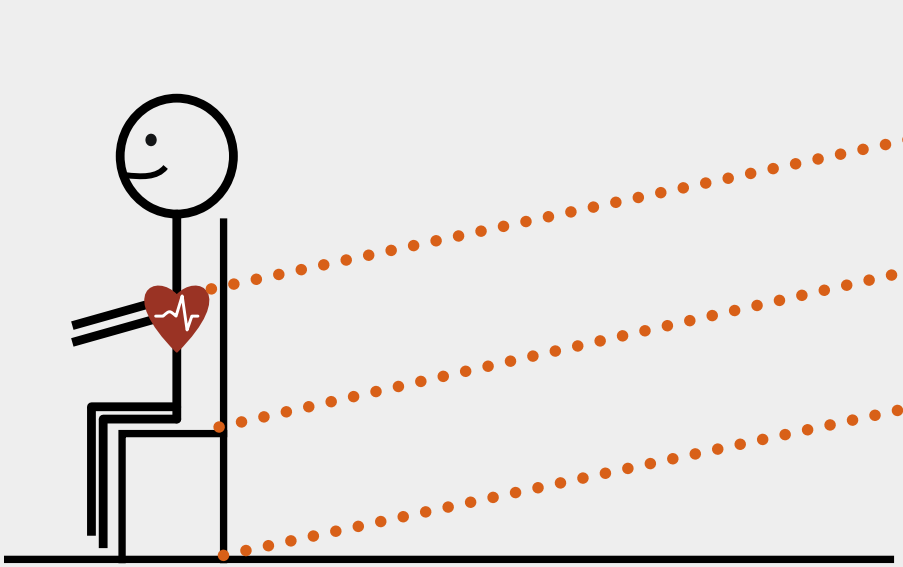

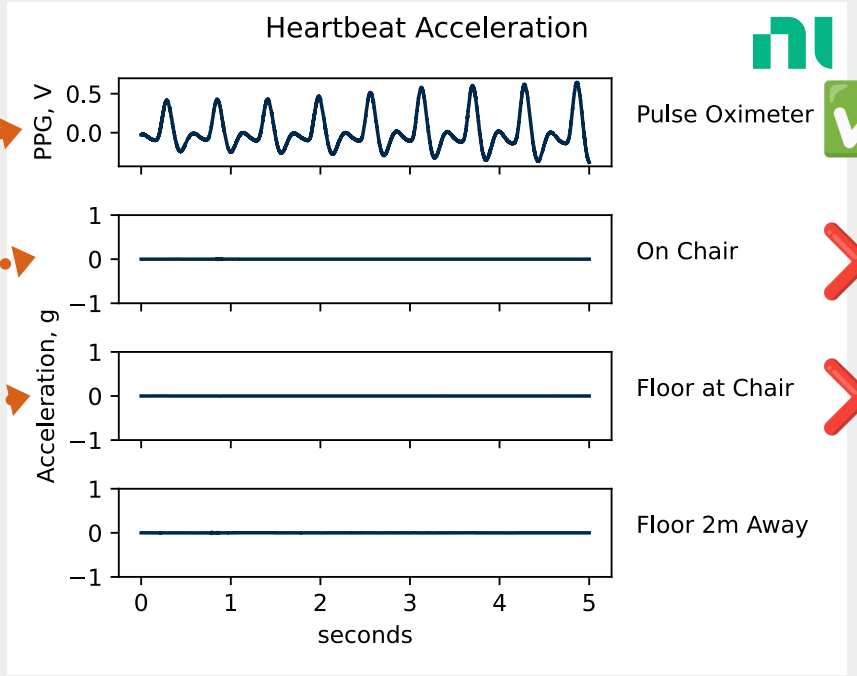

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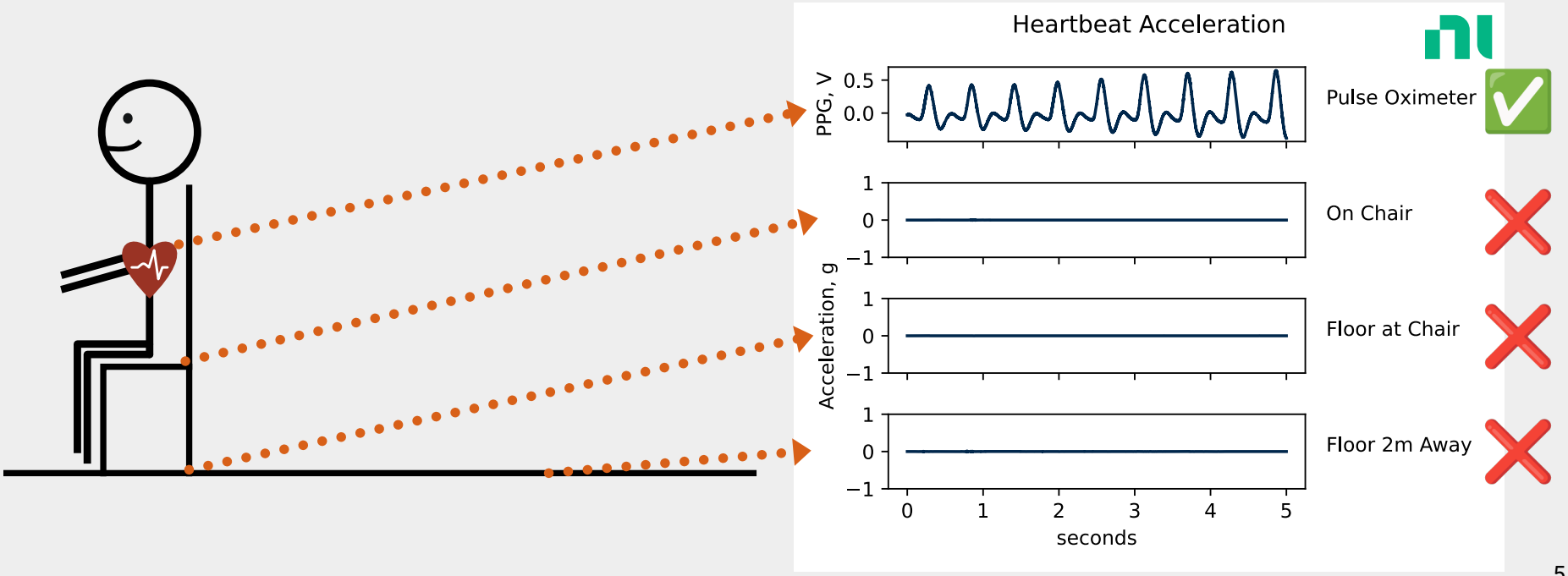

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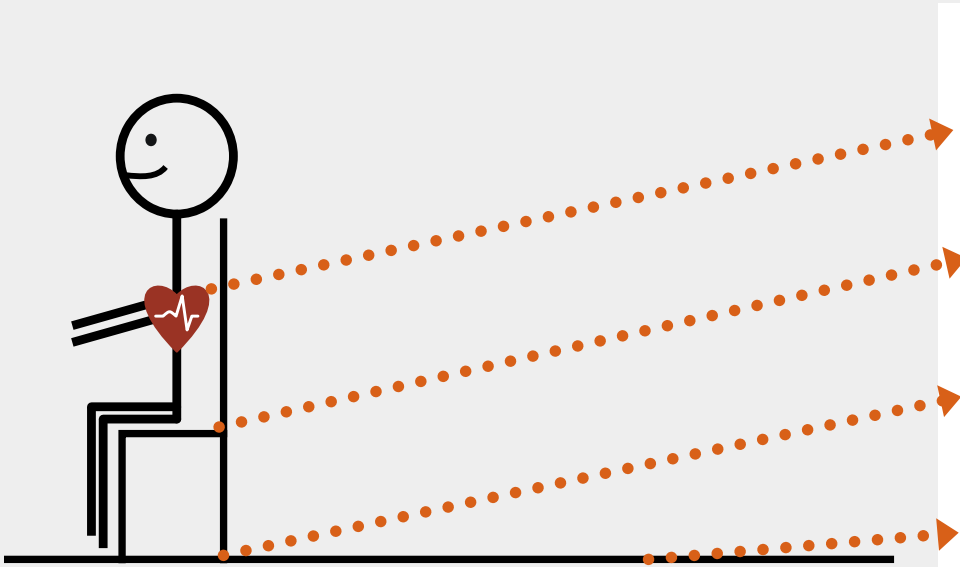
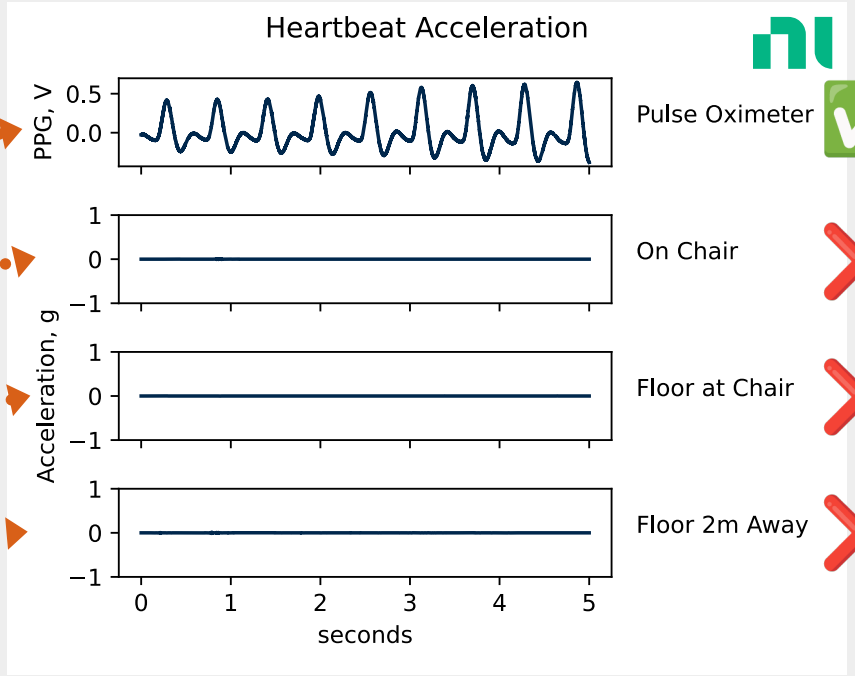
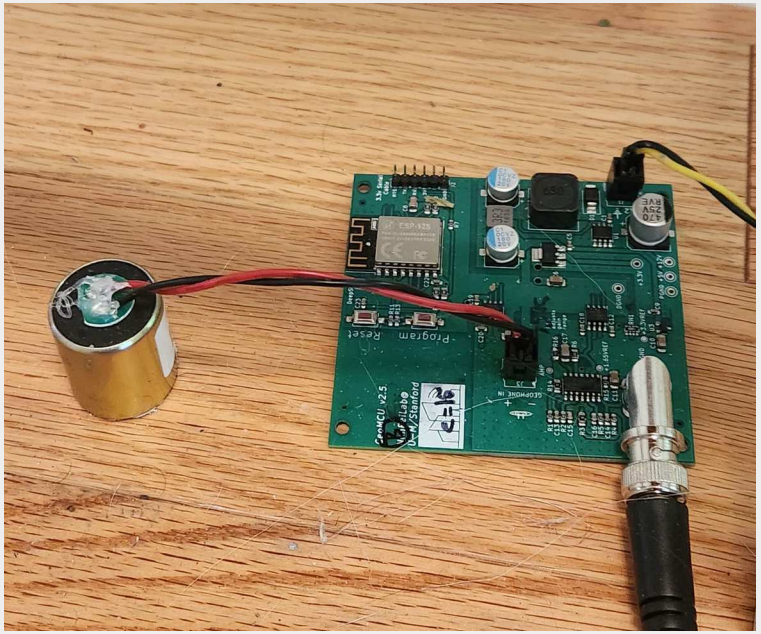




Not with the Accelerometer!

Sensing Hardware for Tiny Vibrations



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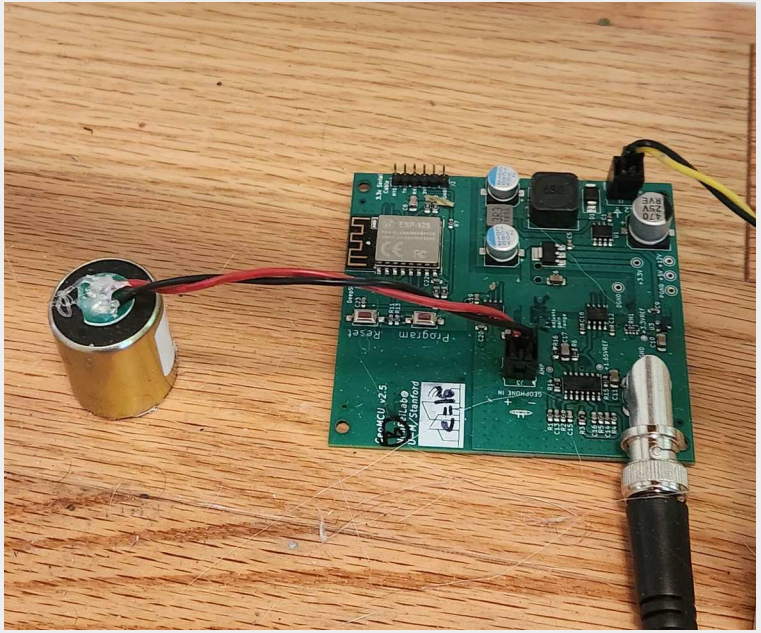

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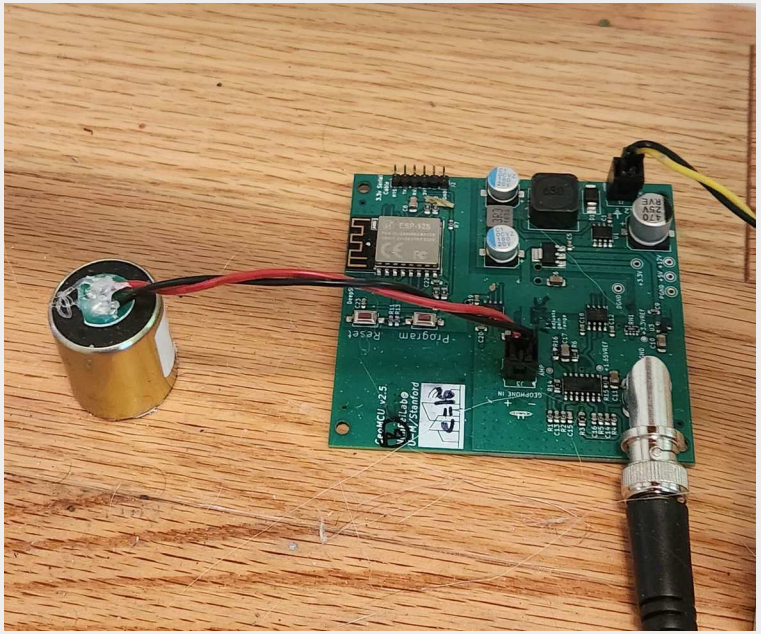

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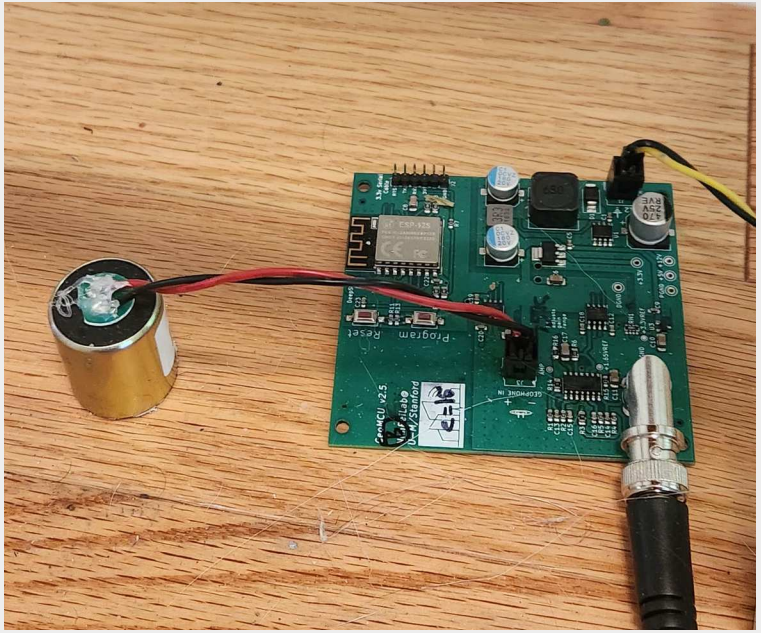

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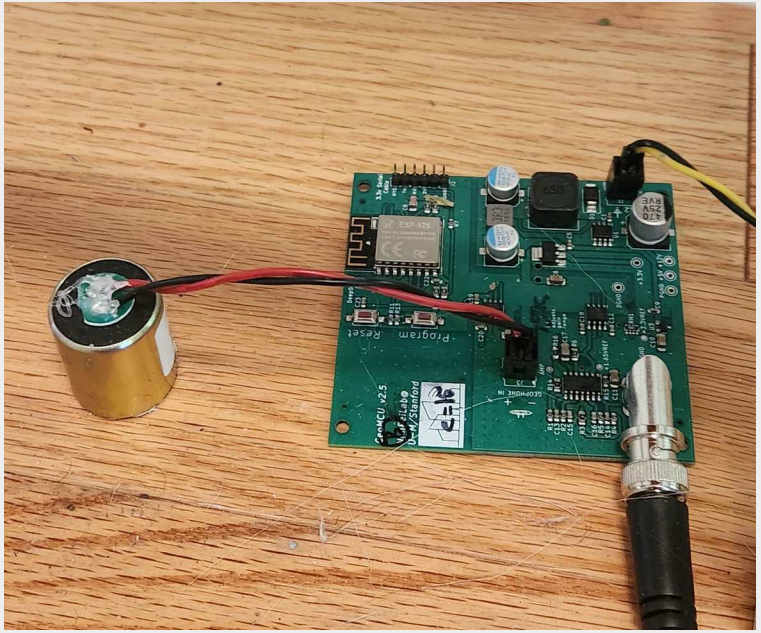

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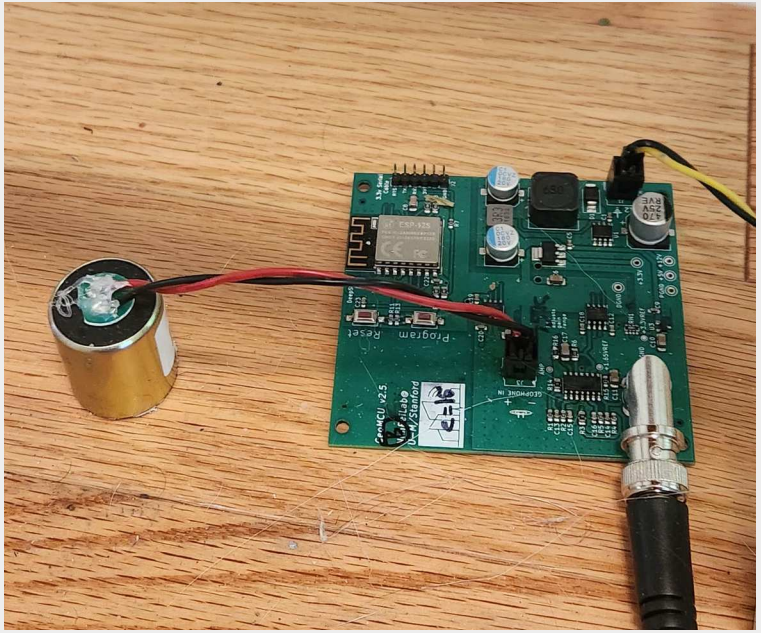

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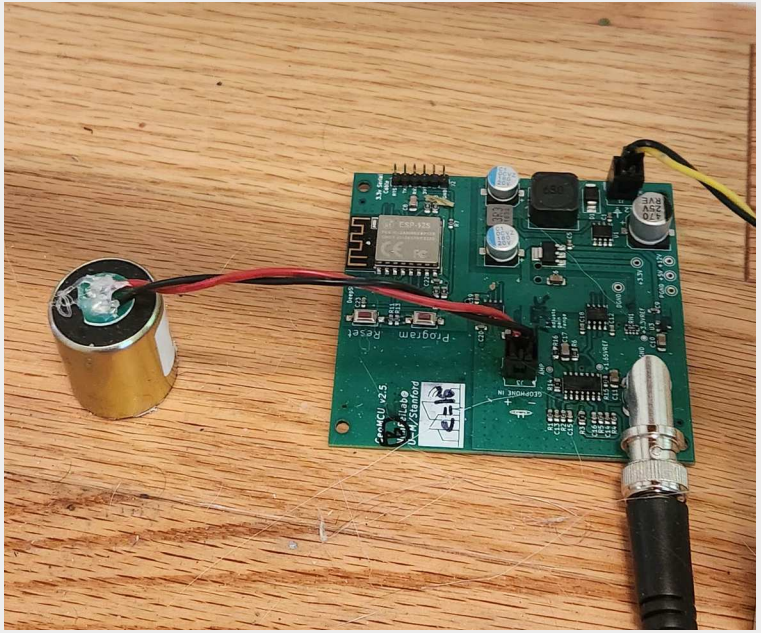

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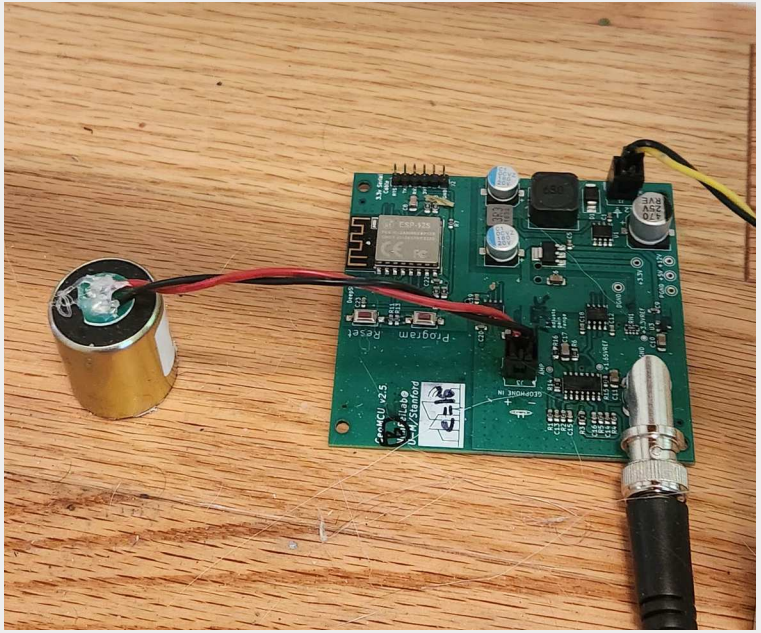
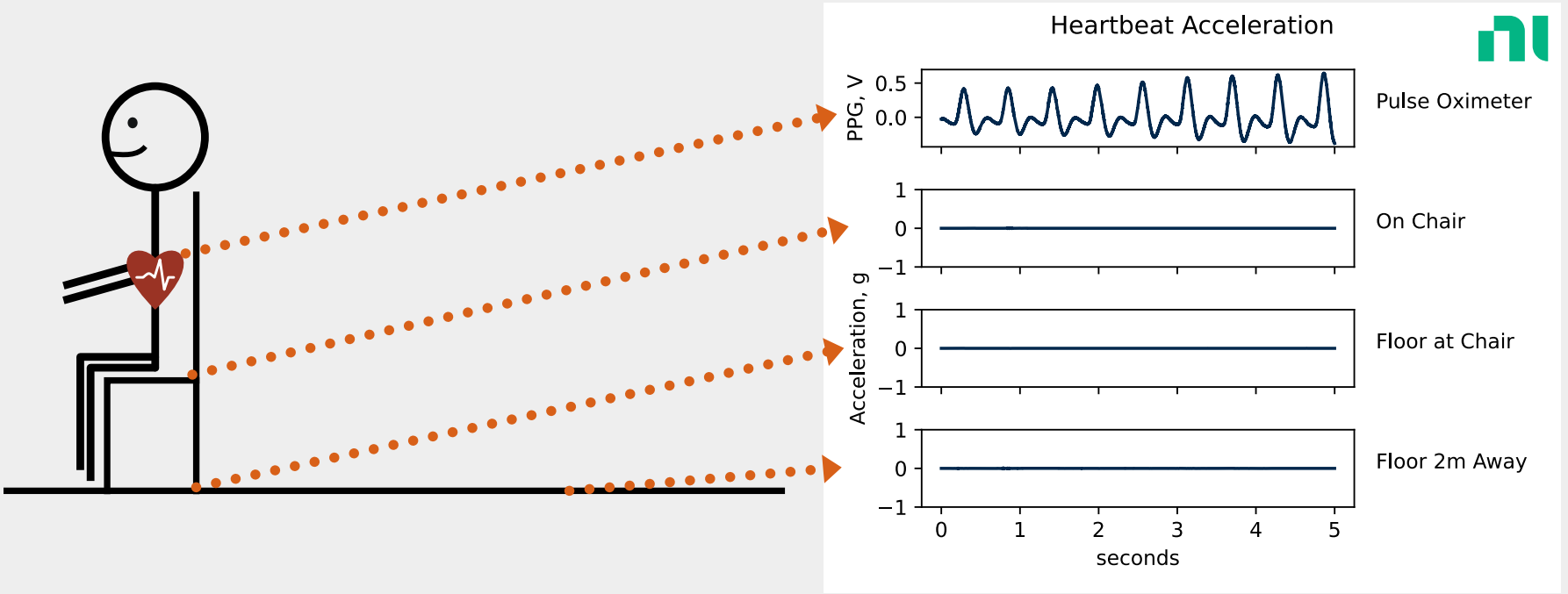


Now Open Source: github.com/NohPei/GeoMCU

Now can we sense Heartbeat-Induced Vibrations?



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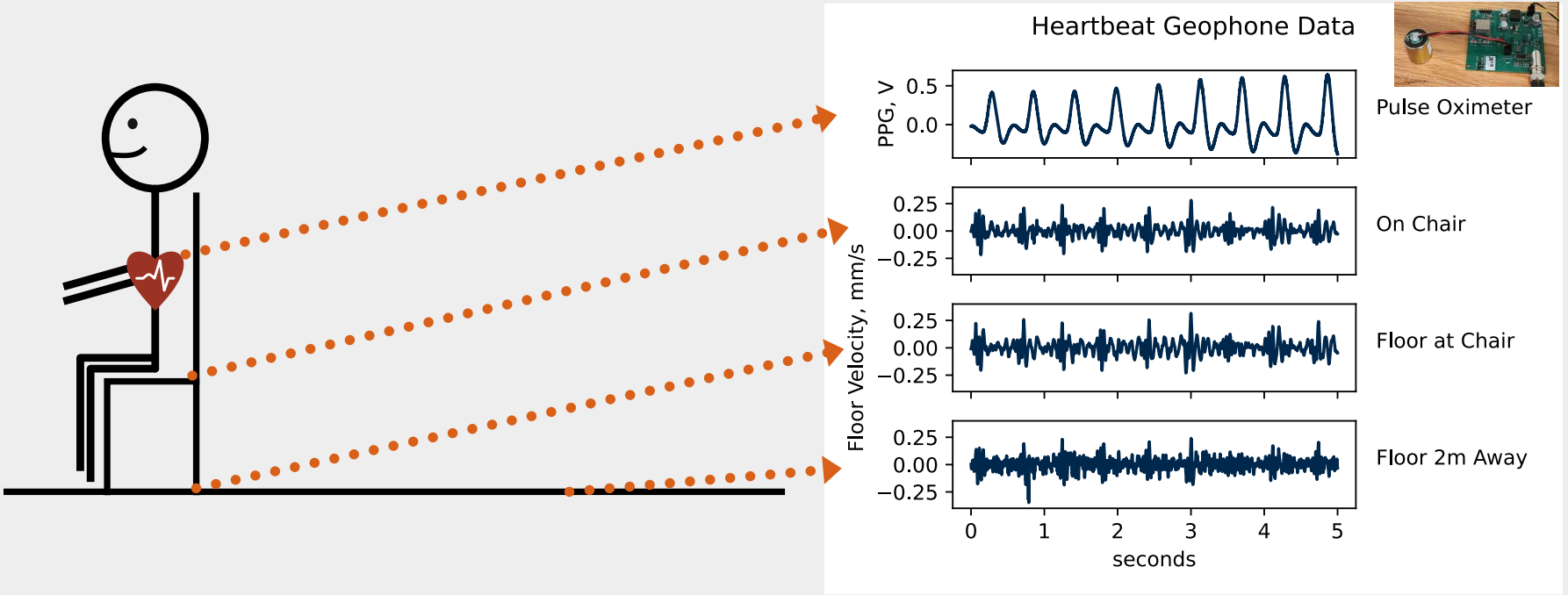

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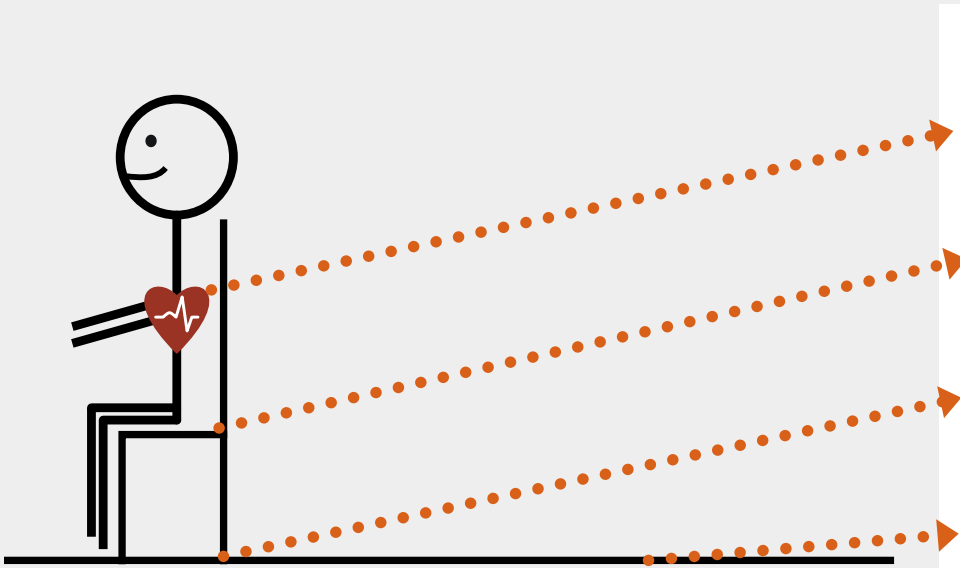

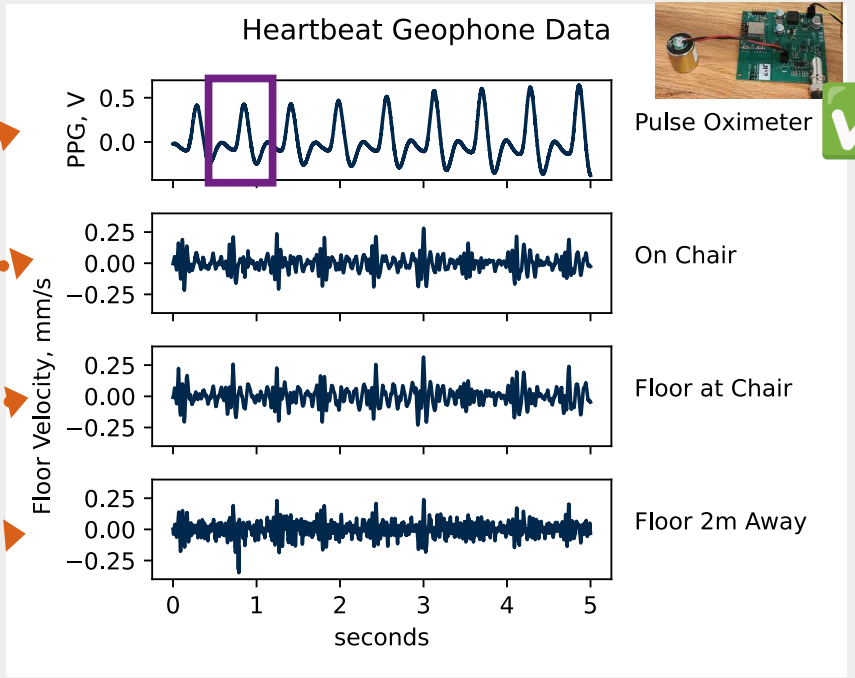

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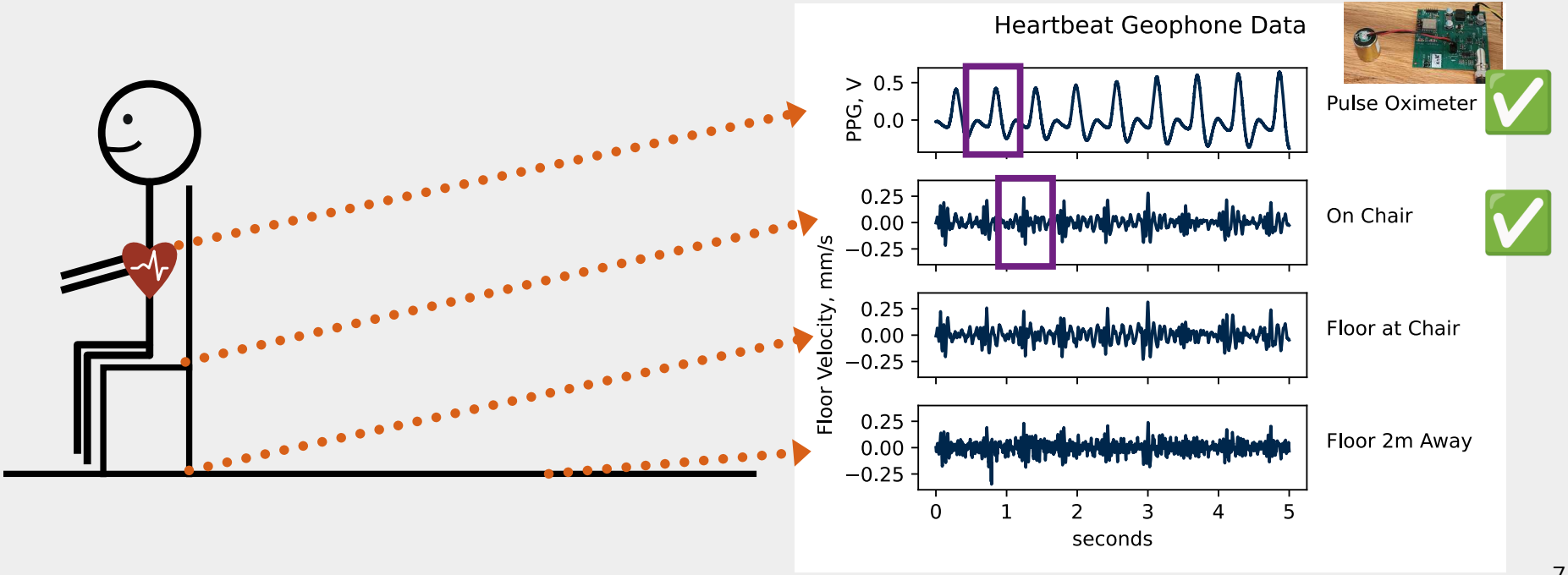

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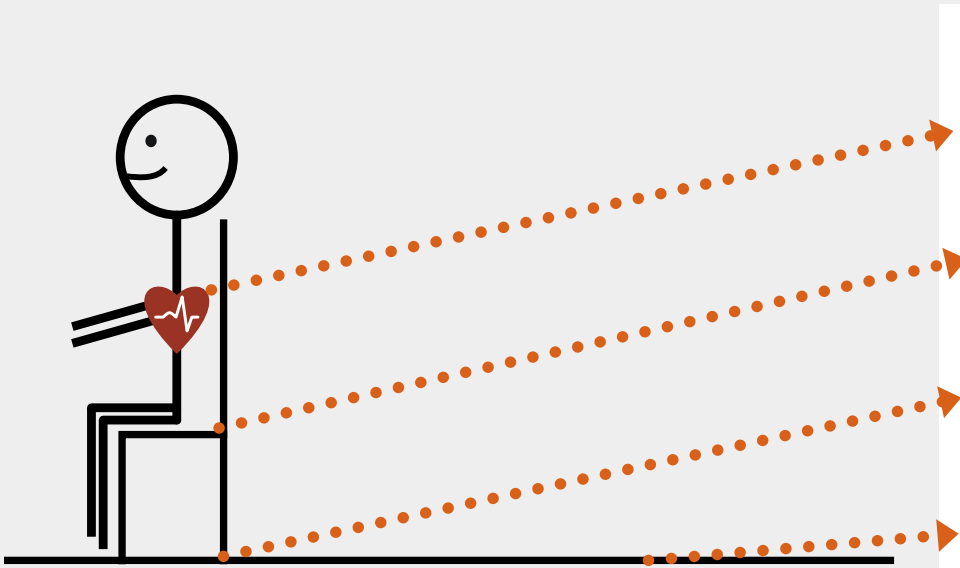

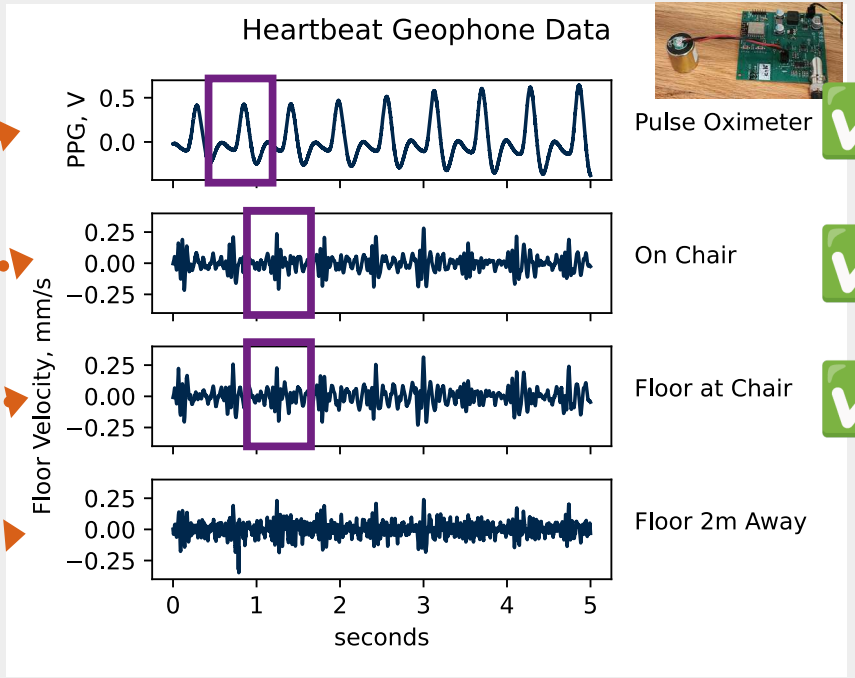

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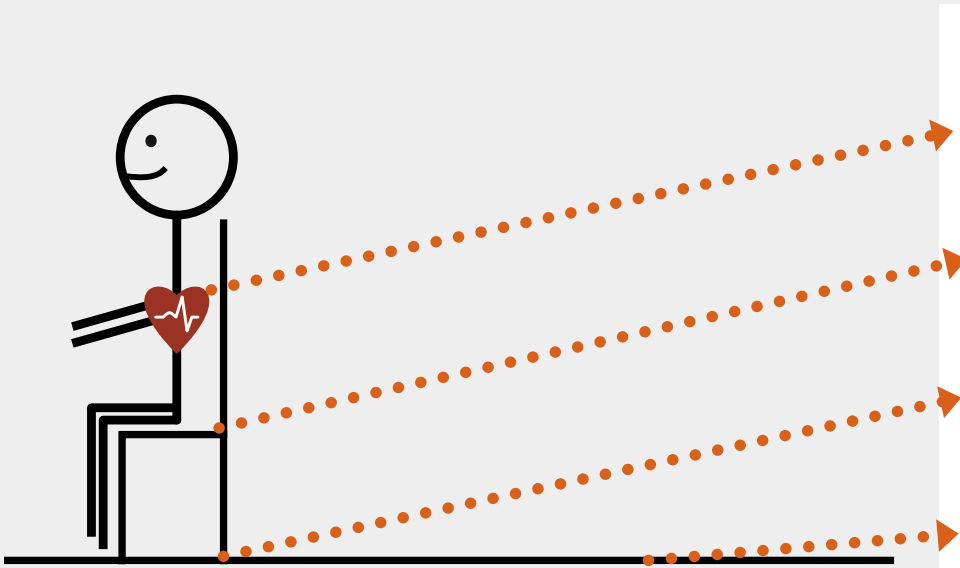

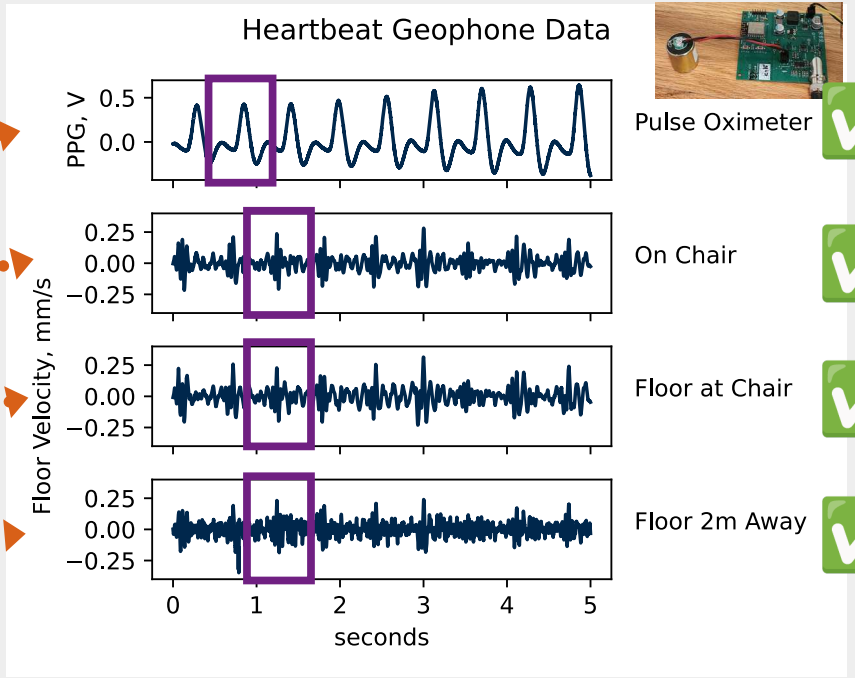

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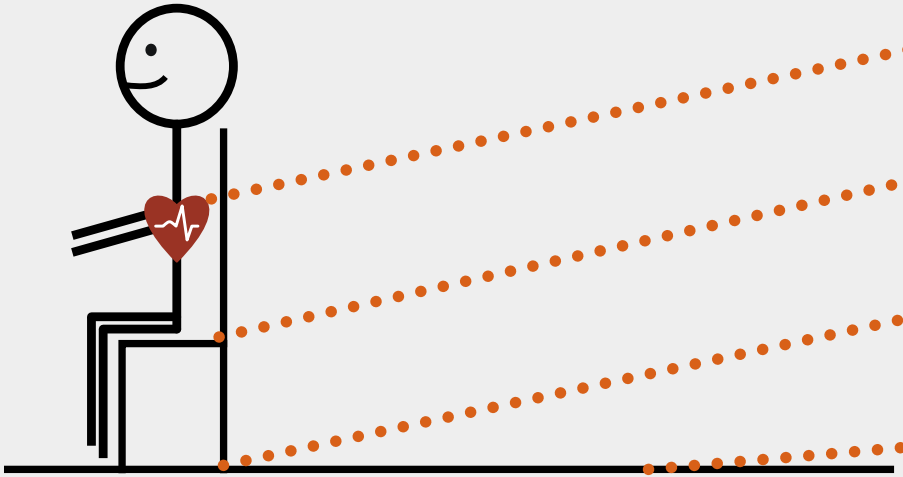
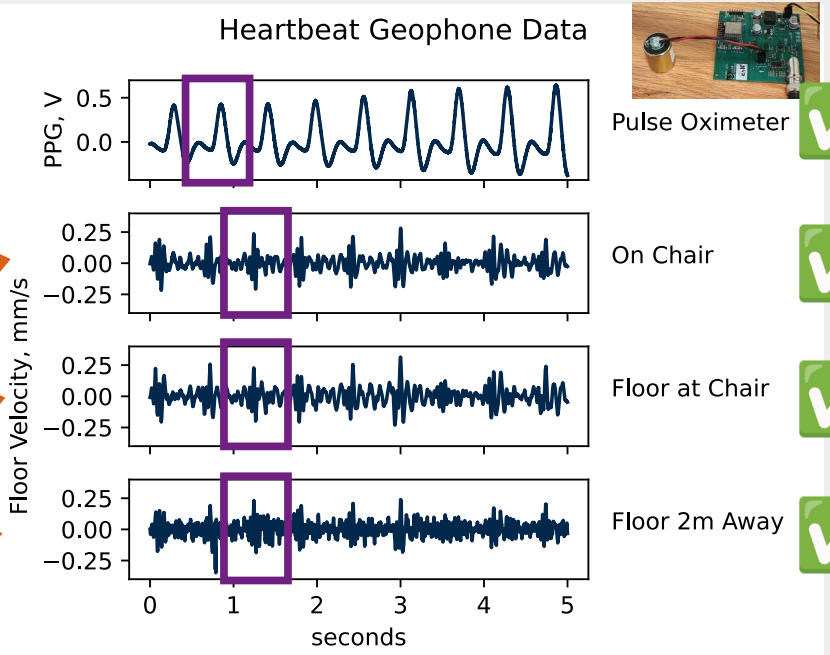
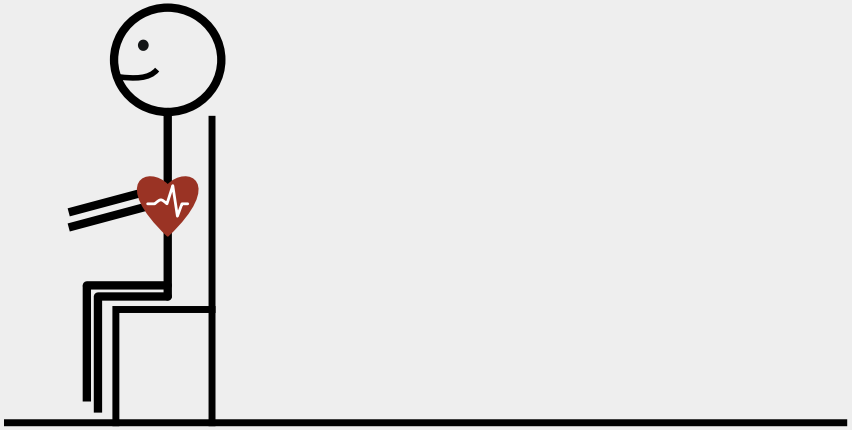


YES!



Heartbeat-Induced Floor Vibrations are HARD!



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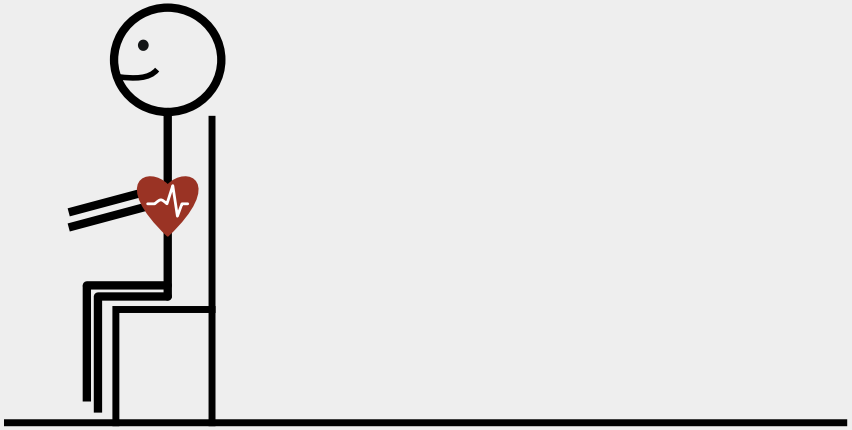

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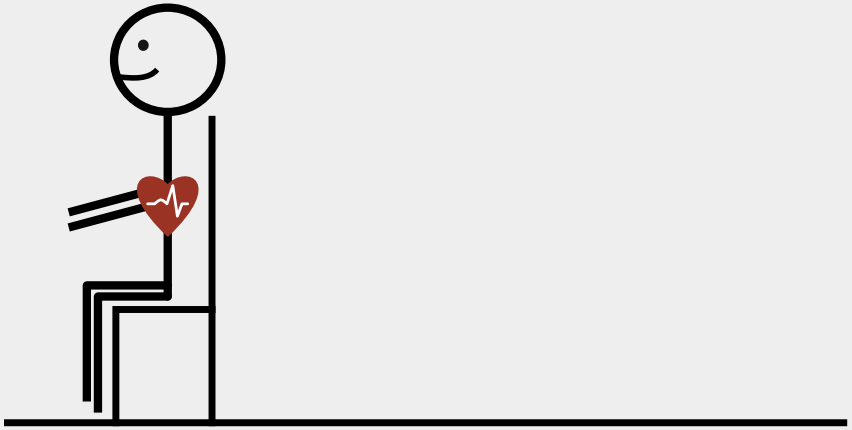

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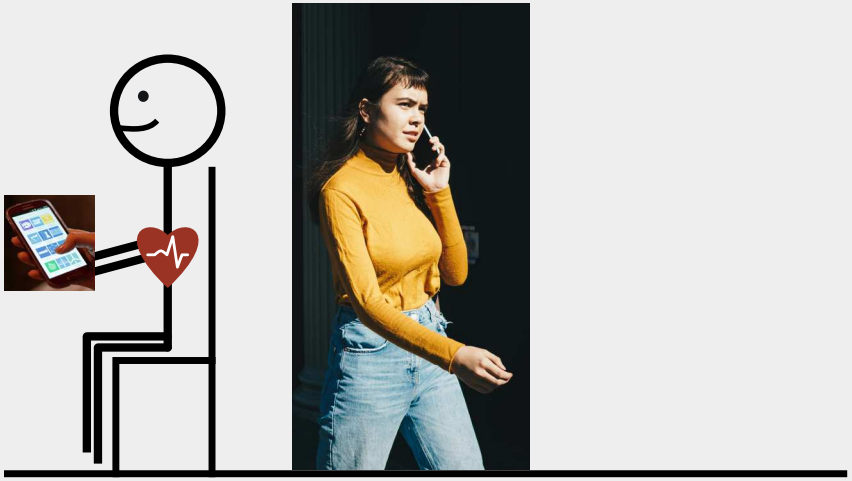

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- Heartbeat vibration is still extremely weak
- MANY vibration noise sources, condensed to two types:
  - **Short-Term Noise**, similar duration to heartbeats
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- Floor and chair materials spread out pulses in **time** and **frequency**

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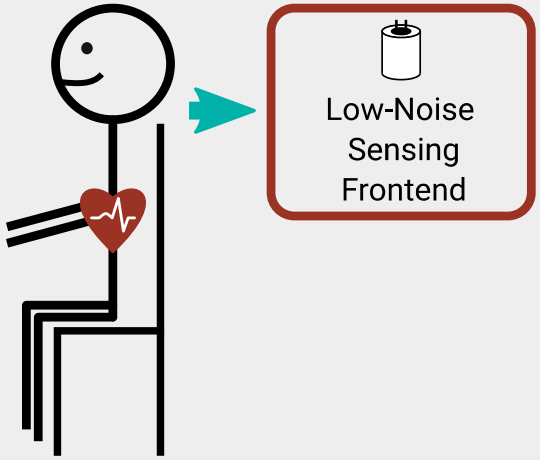

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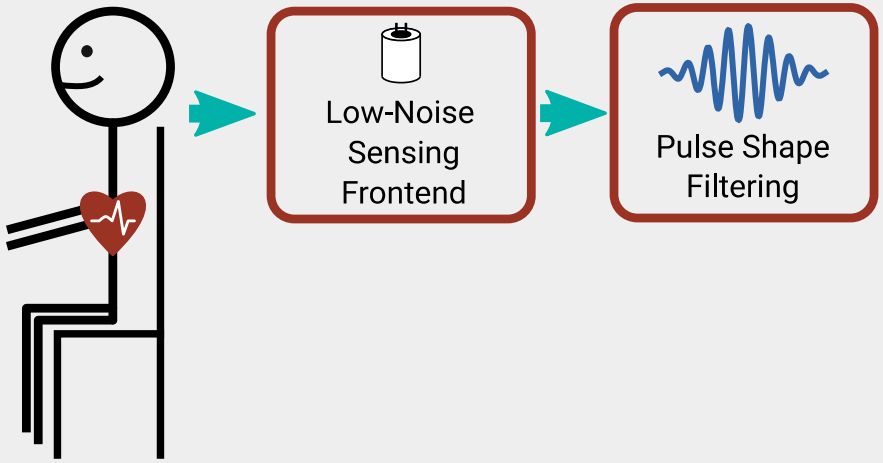

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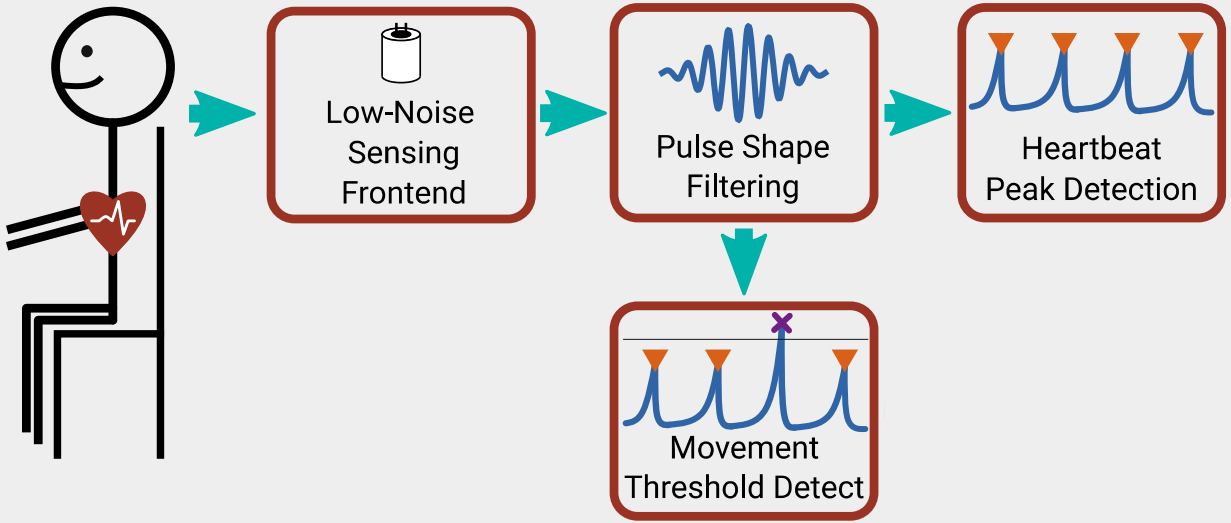

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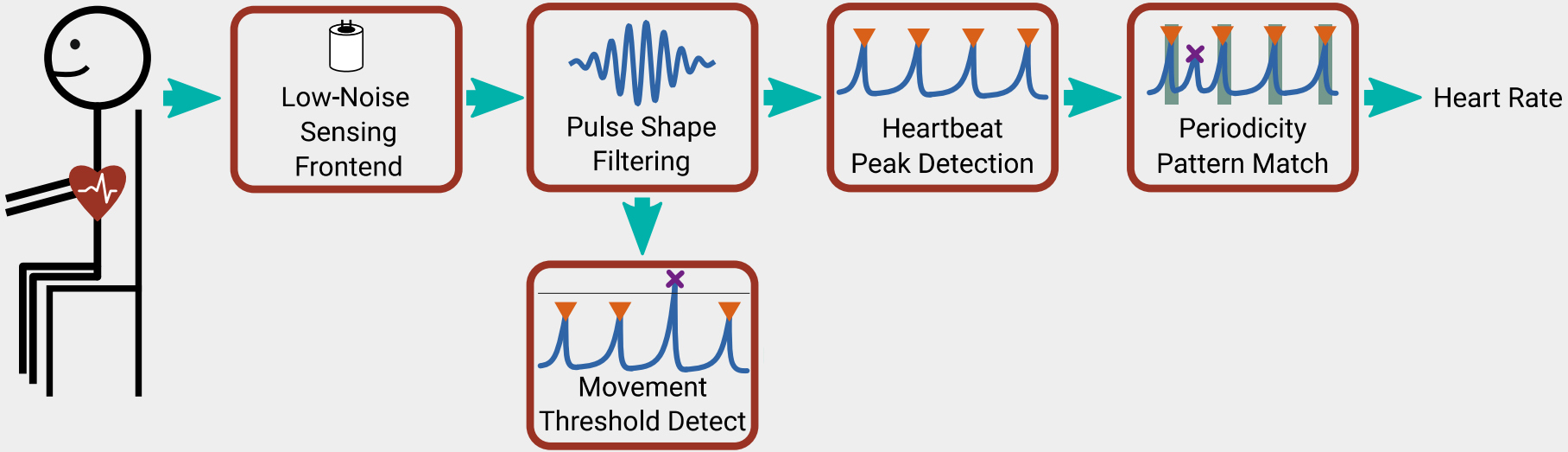

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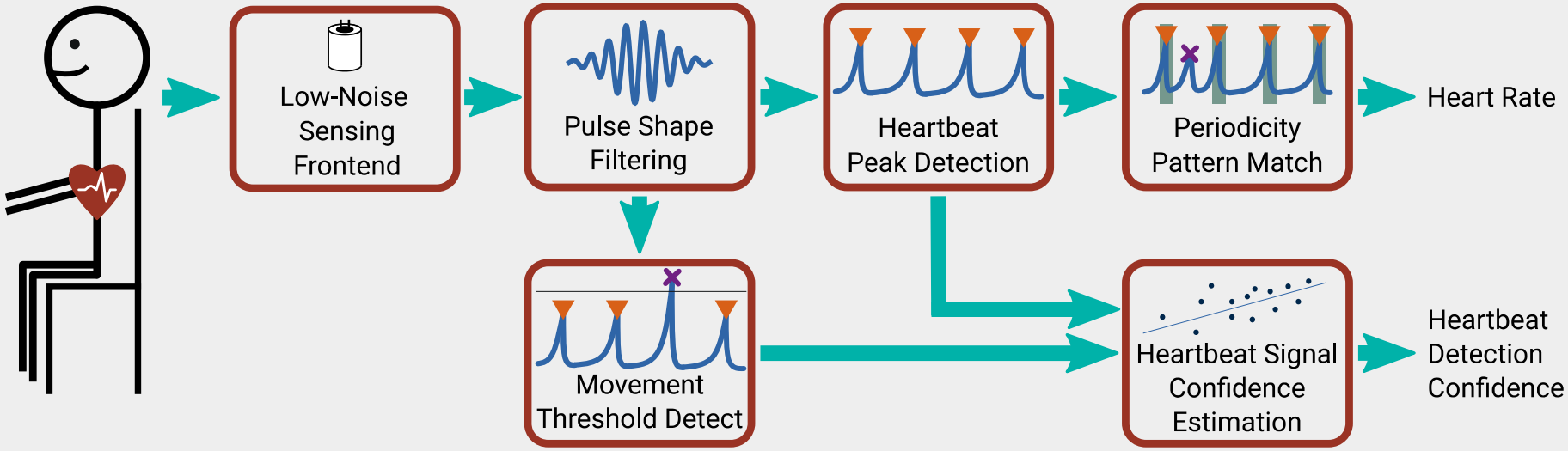

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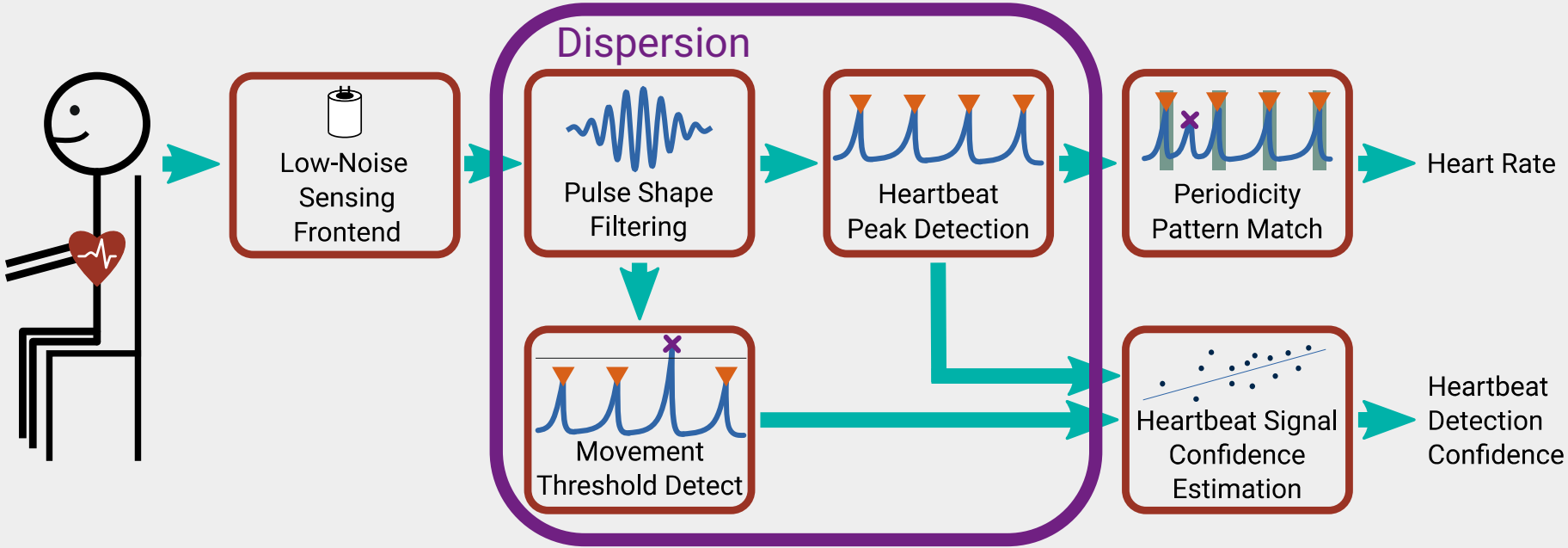

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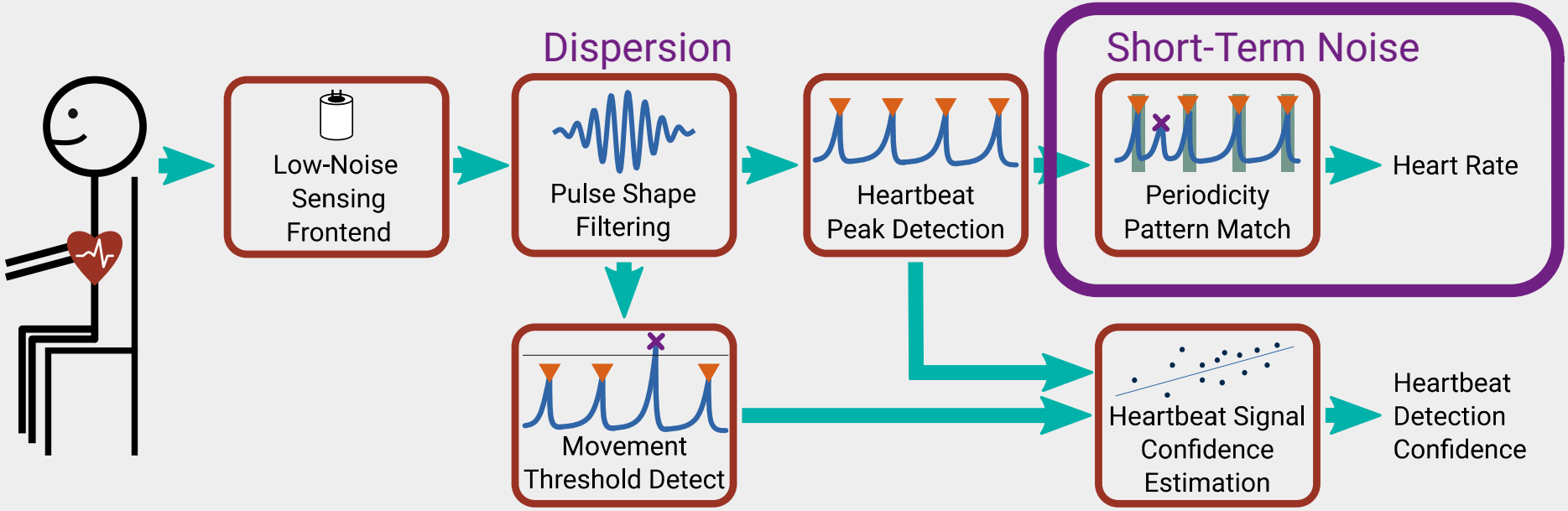

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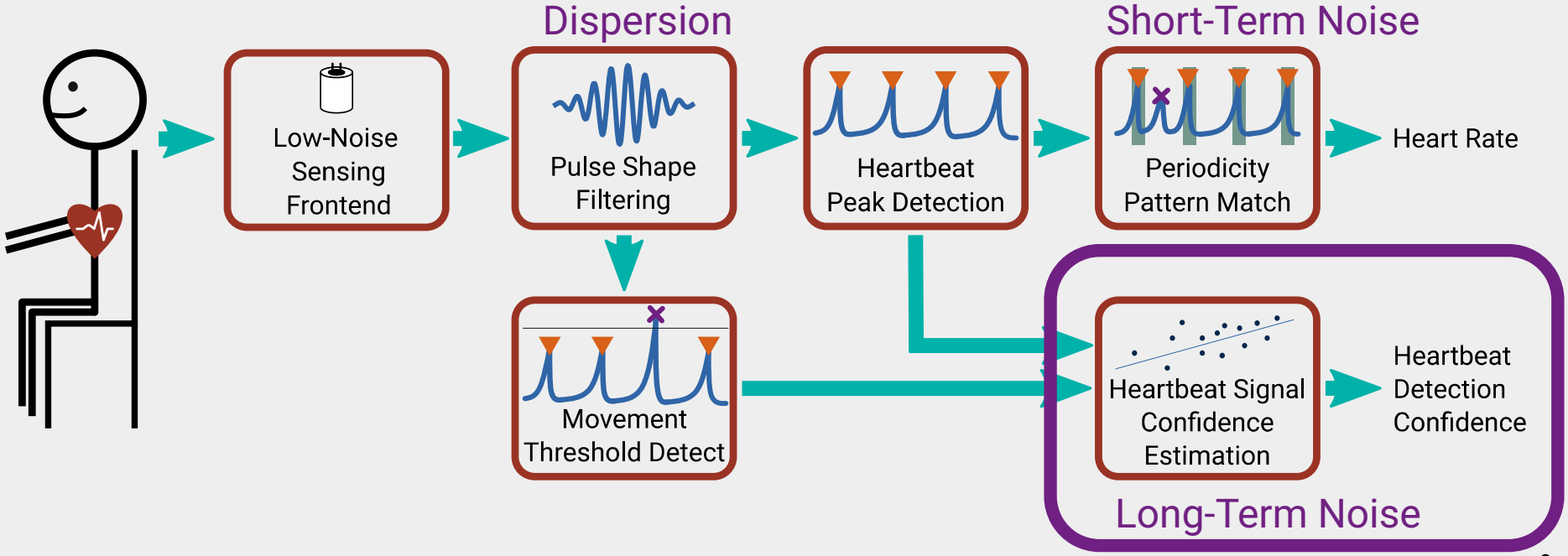

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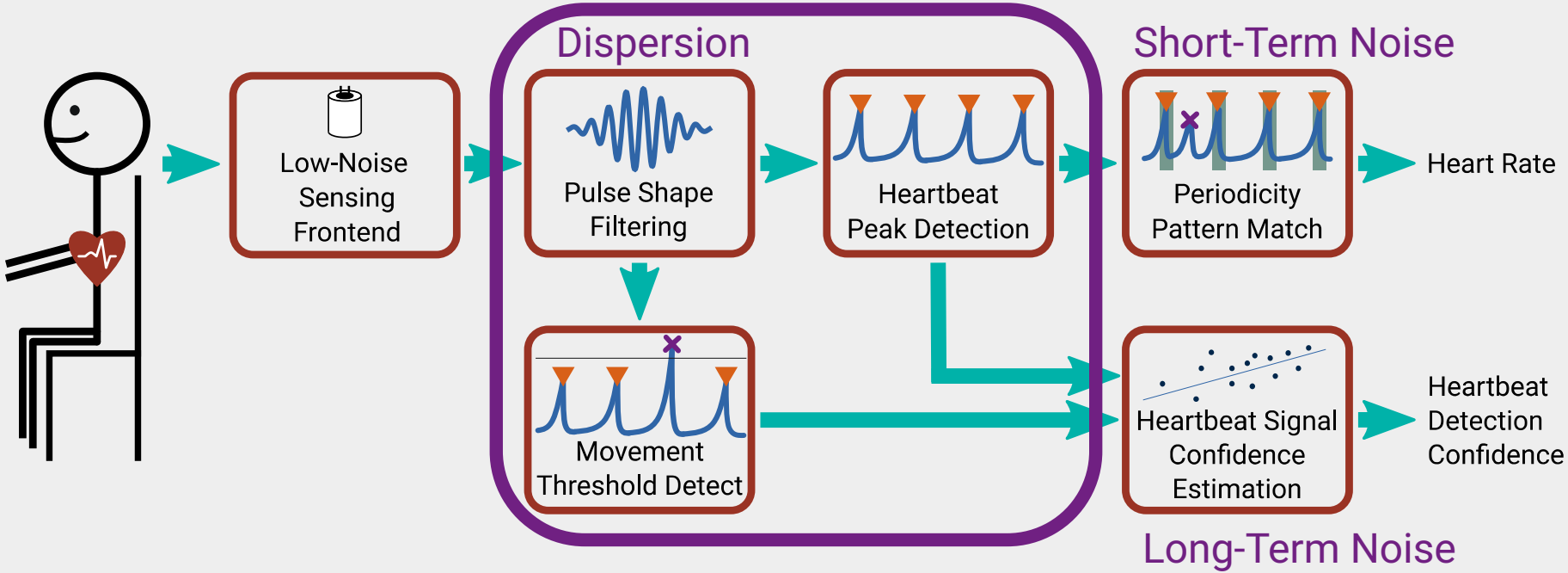

Filtering for Heartbeat-Induced Floor Vibrations

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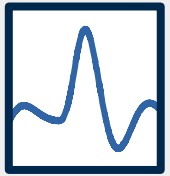
Pulse



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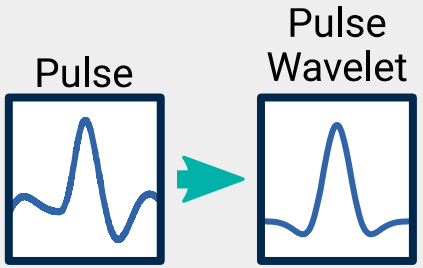

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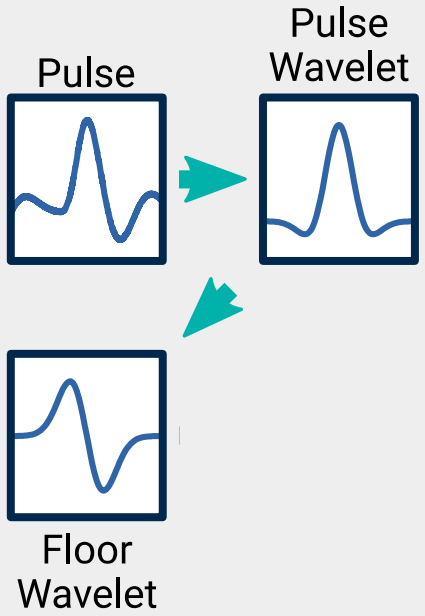

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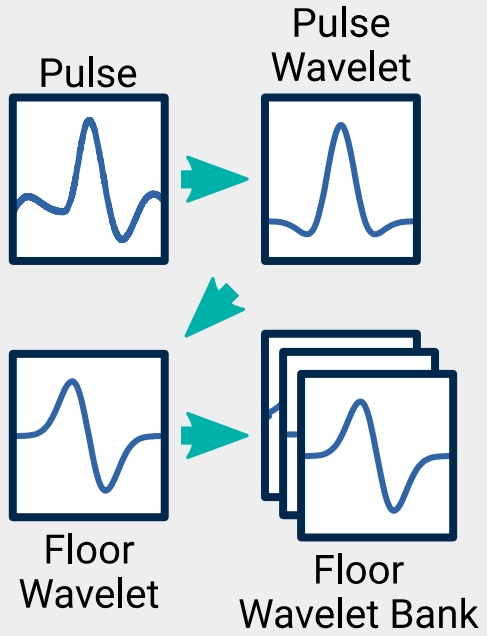
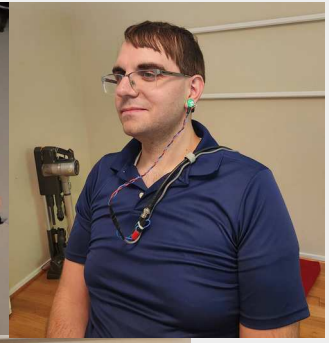
- Matched filter is infeasible: frequency content depends on **floor structure** and subject **physiology**
  - Heartbeats are wavelet shaped!
- Since precise frequencies vary between people, form a **wavelet filter bank** with multiple scales covering the floor's response range



Real World *FloHR* Evaluation!



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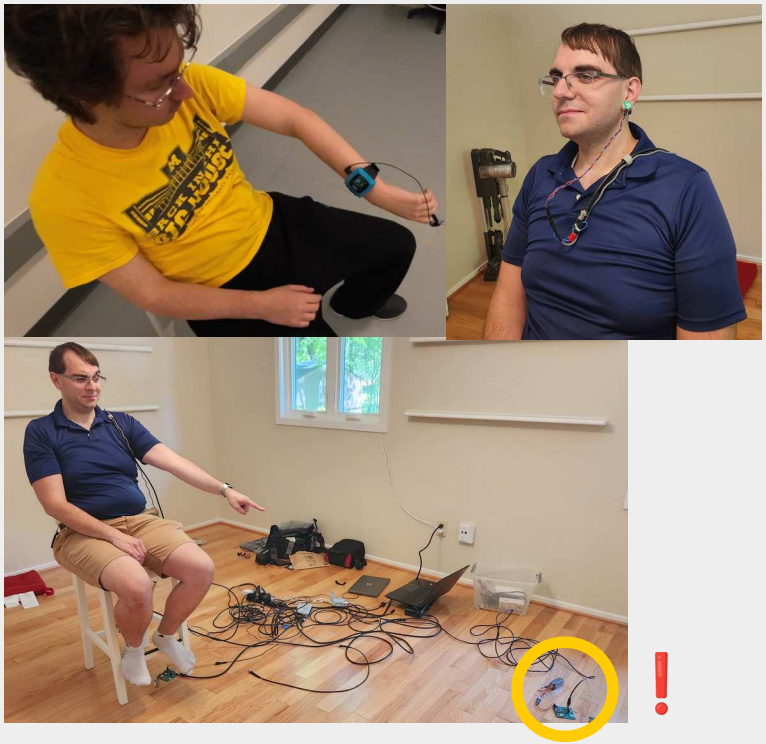

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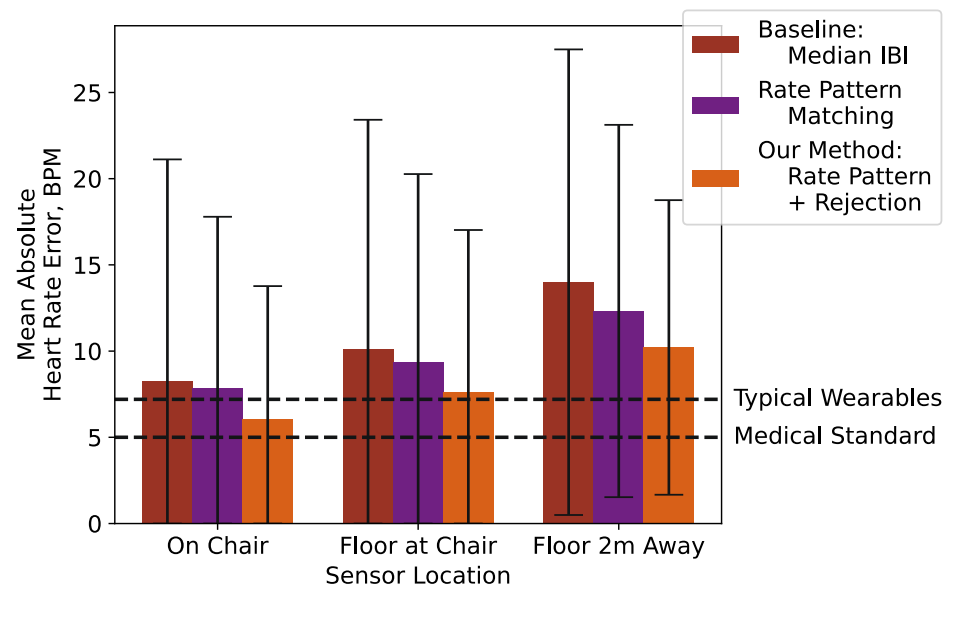
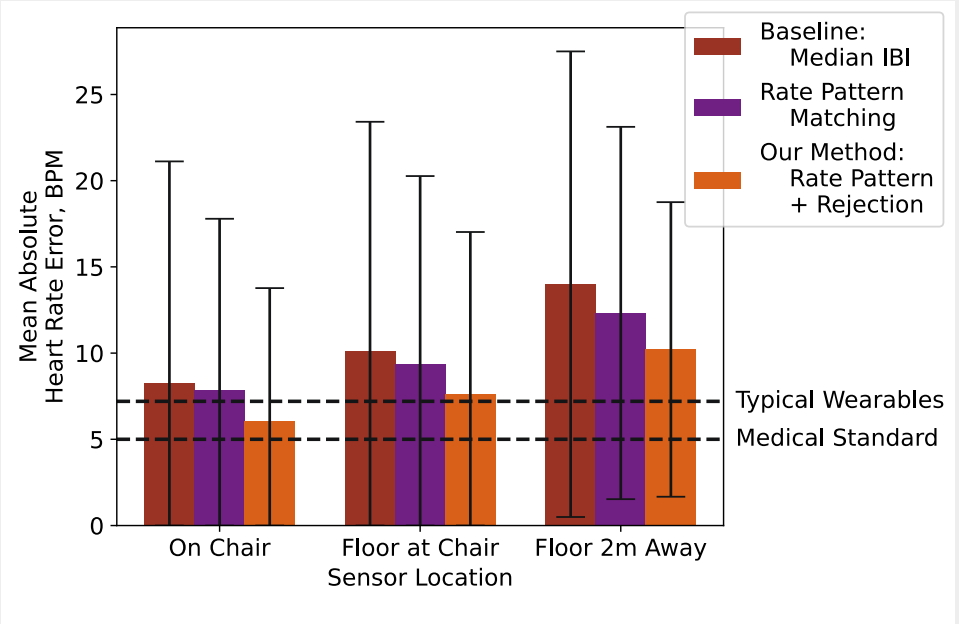
  - Below Chair on Floor
  - **2 meters away** on Floor
- **Ambient noise** from home environment:
  - Conversation
  - Toilet flushing
  - Footsteps in next room
  - Smartphone screen touches

Heart Rate Accuracy: *FloHR* can do it!



Heart Rate Accuracy: *FloHR* can do it!

- *FloHR*'s vibration noise handling **reduces error** in detected heart rate by at least **25%**



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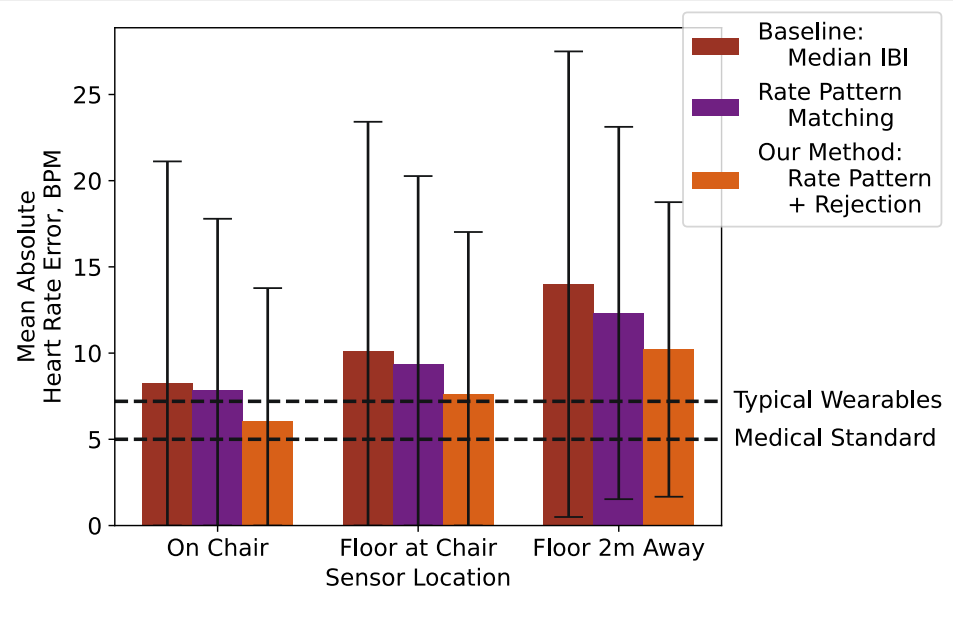

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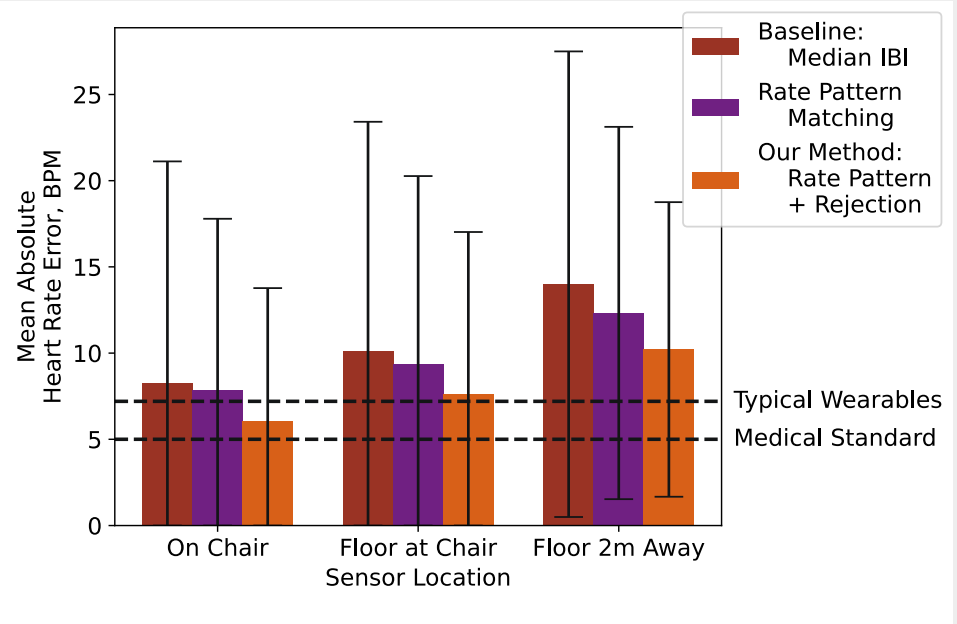
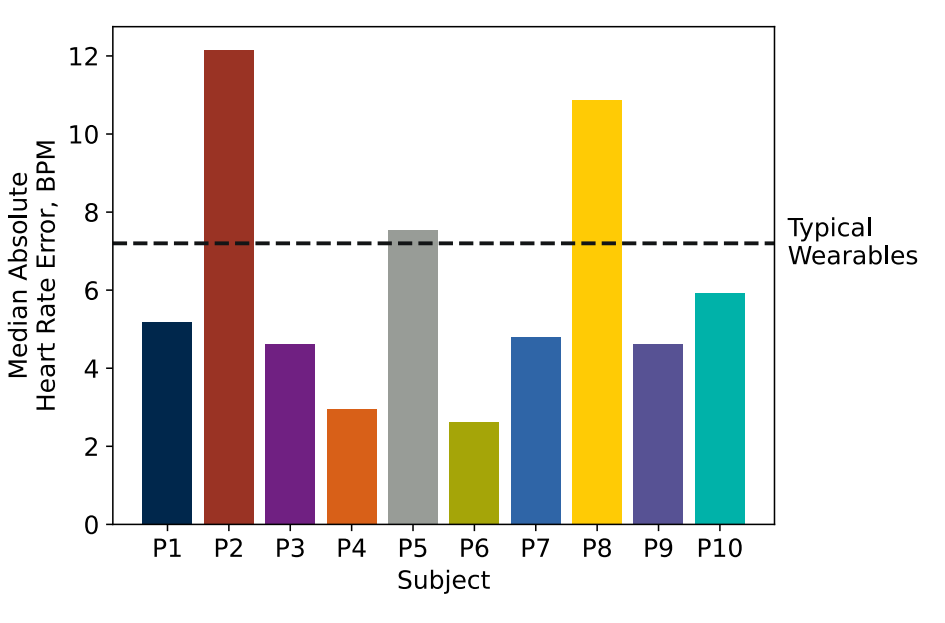
- At **2 meters** away, *FloHR* still measures heart rate with an average error of only **10 bpm**



Heart Rate Accuracy with Multiple People



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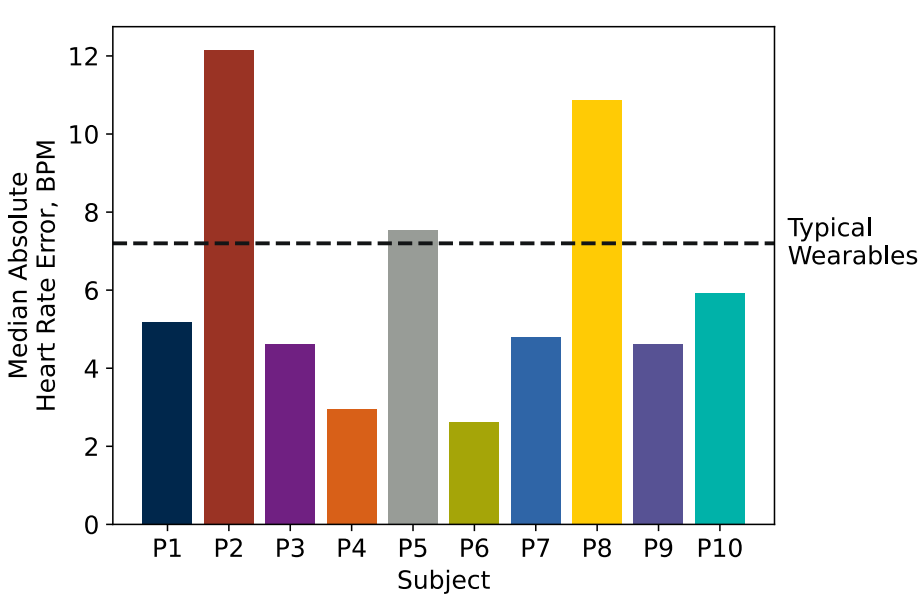

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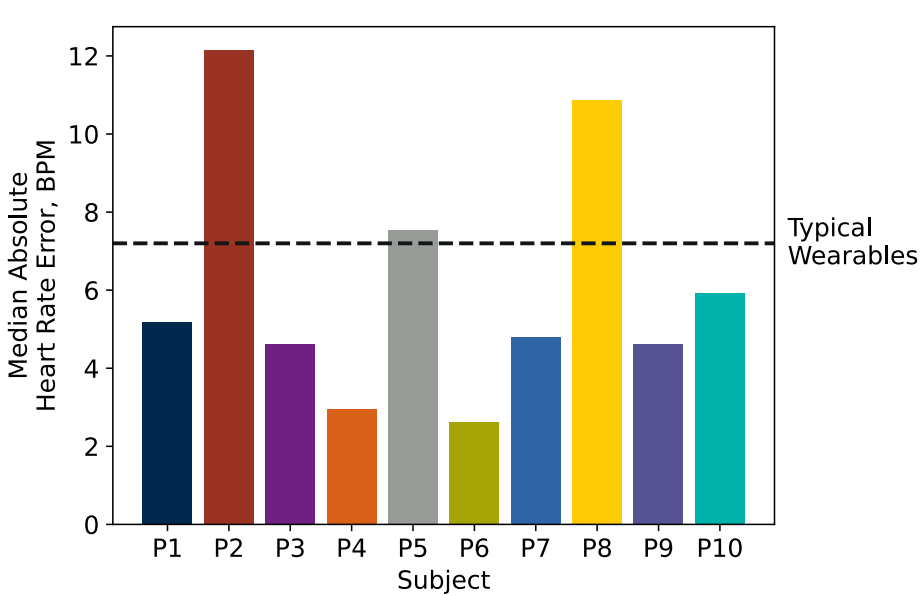

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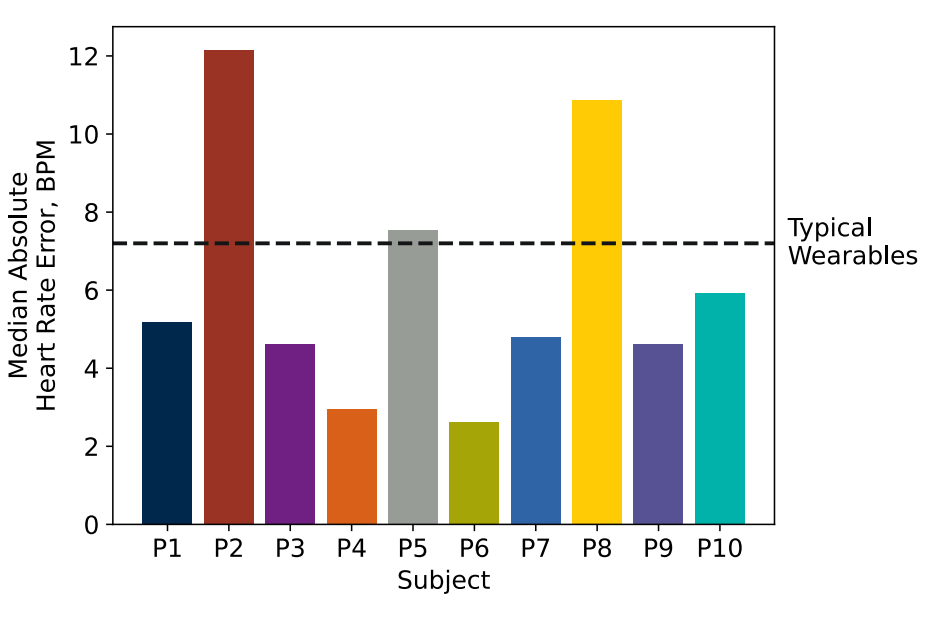

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- Performance varies between people based on physiological and health characteristics
- Median heart rate error for the most difficult users is still below **12 bpm**

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- We evaluated with 10 different people in a real home environment, achieving **10 bpm** average heart rate error at 2 meter distance.
- *FloHR*'s accuracy varies with individual characteristics, particularly cardiovascular abnormalities

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Structures as Sensors

Thank You!