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Wireless Wearable Triage & Health Monitoring Device for MCIs and First Responders

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2021-04-28

Background - MCI

- Mass Casualty Incident (MCI)
  - Response need is greater than available response resources
  - Emergency Services may be overwhelmed
  - Chaotic, Dangerous Environments
  - Difficulties in tracking responders and people who require care
  - Often requires Triage

Source: Wikimedia Commons

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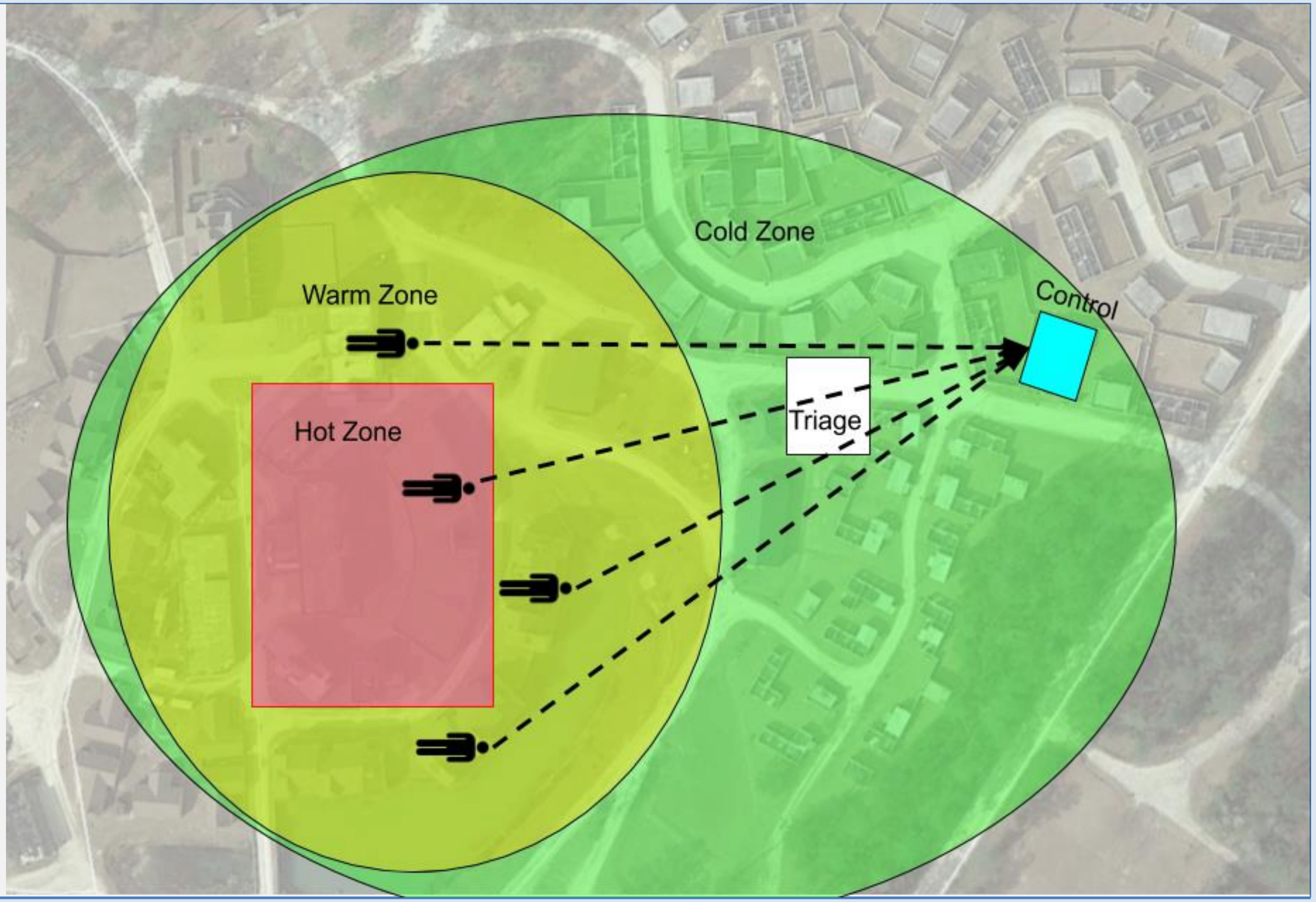
Background – NIMS/MCI Management

- Zones
  - Hot
  - Warm
  - Cold
- Control
- Triage



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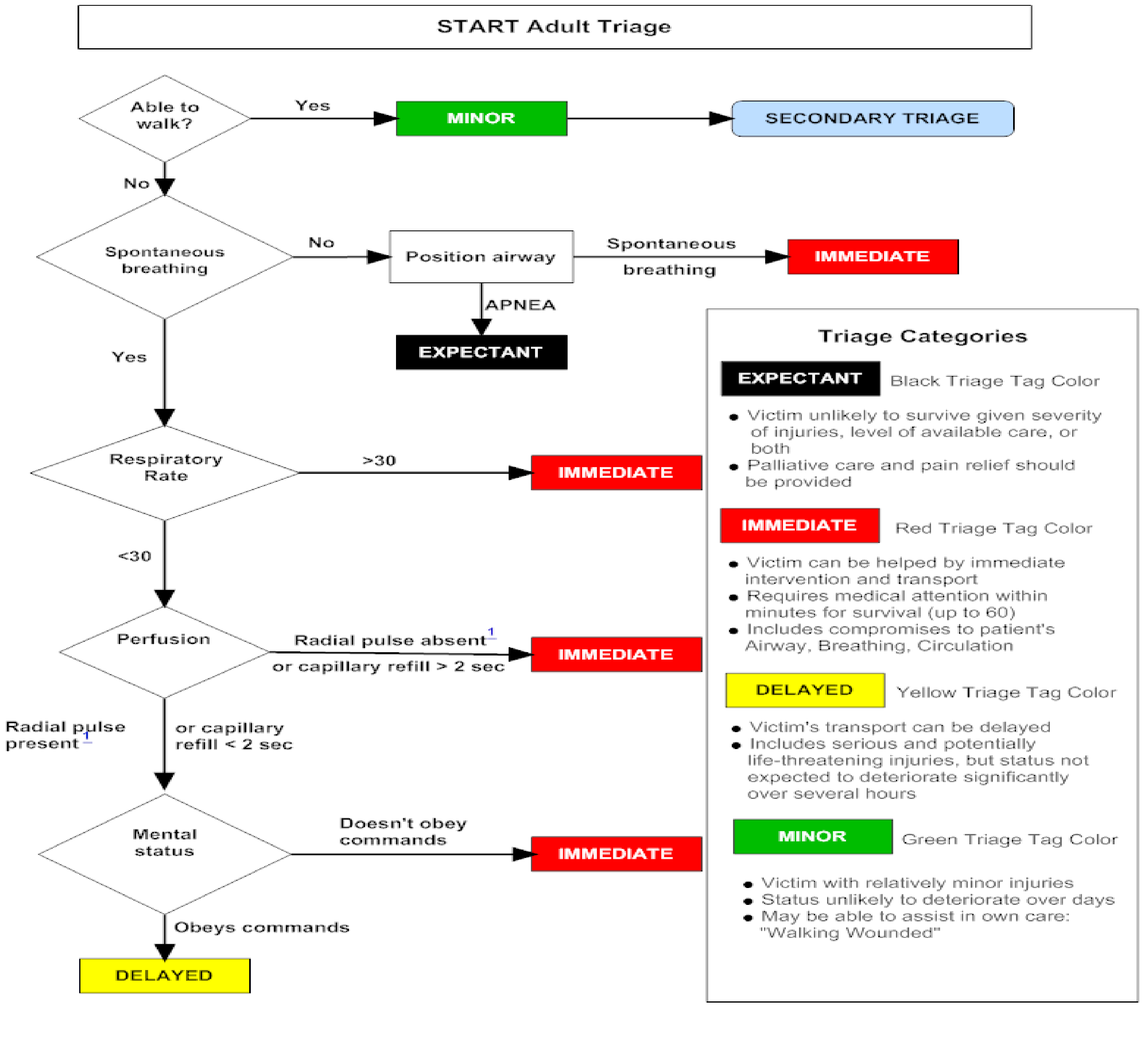
Background - Triage

- START triage
  - RPM 30-2-Can Do
  - Limitations:
    - Single Moment
    - Doesn't Consider "Delayed" to "Immediate" transition
    - May be oversimplified
    - No resource management defined



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Background – MCI Recent Examples

Source: Aaron Tang via Wikimedia Commons (CC-BY-SA 2.0)

- Boston Marathon Bombing (2013)
  - 264 Wounded (17 Amputations), 3 Dead
  - 15 block response area, with potential threat of secondary bombs
  - Cell network overload

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Background - MCI Recent Examples

Source: Jennifer Morrow via Wikimedia Commons (CC-BY 2.0)

- Las Vegas Shooting (2017)
  - 60 Dead, 411 wounded by gunfire, total wounded 867 due to panic
  - 15 acre lot used for music festival
  - Rapid treatment, and difficulty in moving patients due to road closures

Background – MCI Recent Examples

Source: Mehr News Agency via Wikimedia Commons (CC-BY 2.0)

- Beirut Port Explosion (2020)
  - 215 Dead, 7500 wounded
  - Hospitals at 50% capacity due to COVID-19
  - Damage up to 6 miles from center

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Background – Lessons from Recent MCIs

- Cell Service can be overloaded, complicating response and patient location
- Tracking, and managing flow of patients can be difficult
- Other current medical issues may strain resources

Main Question

Could a device be developed to enhance the ability of first responders to deal with MCIs, by augmenting triage with remote monitoring, to allow for better resource utilization?

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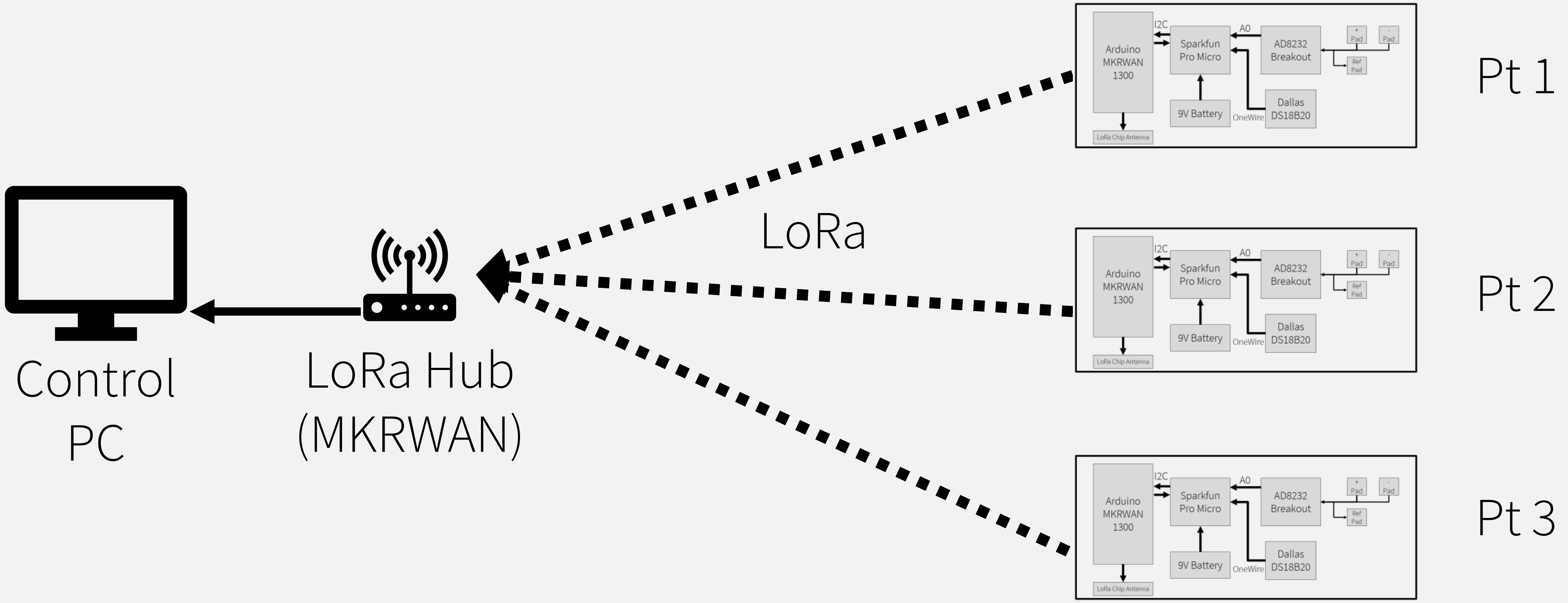
Method

- Small battery-powered wearable patch with quick application
- Measure and process vitals and location on device
- Wirelessly transmit data to central control for logging and monitoring

High Level System Block Diagram



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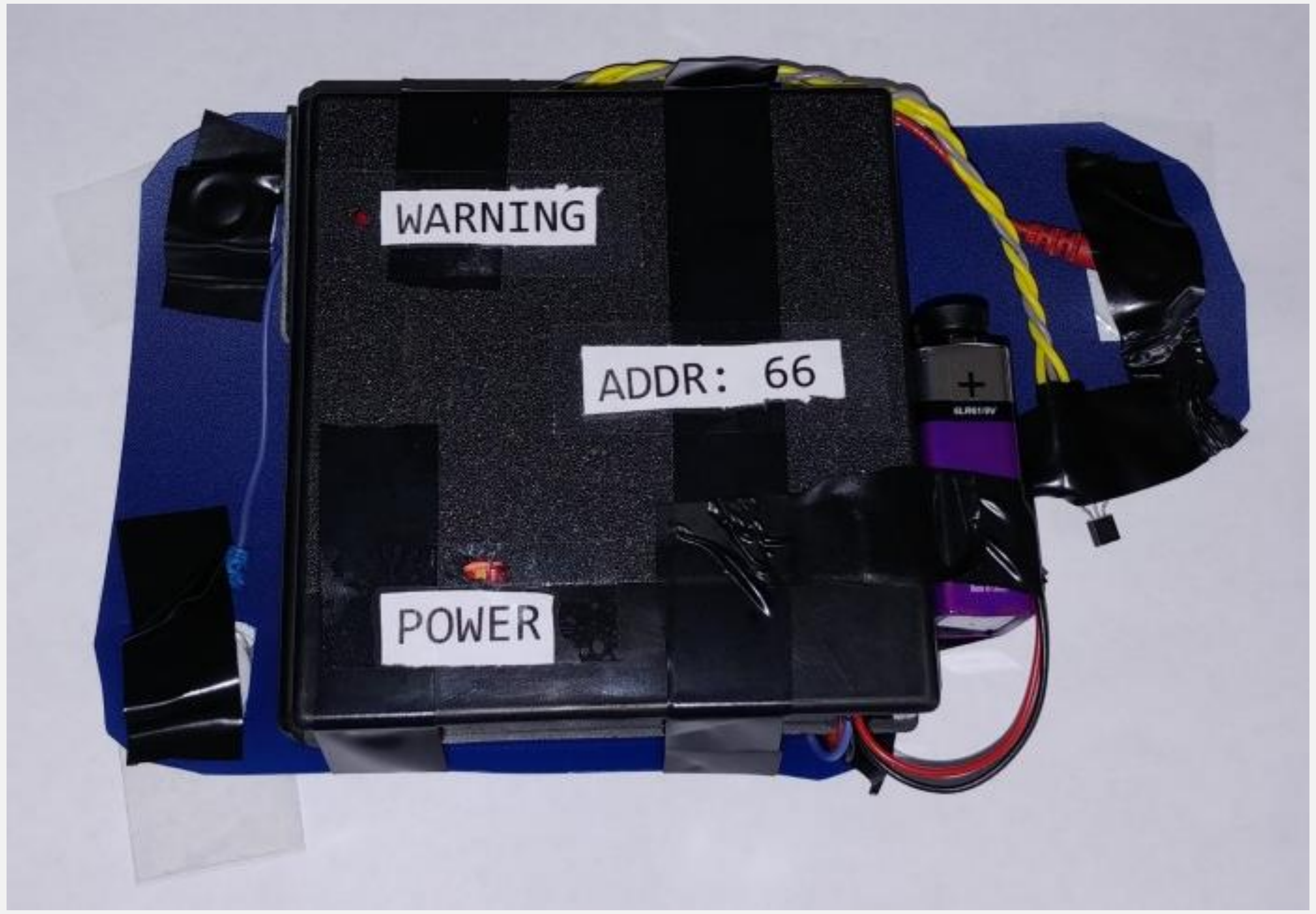
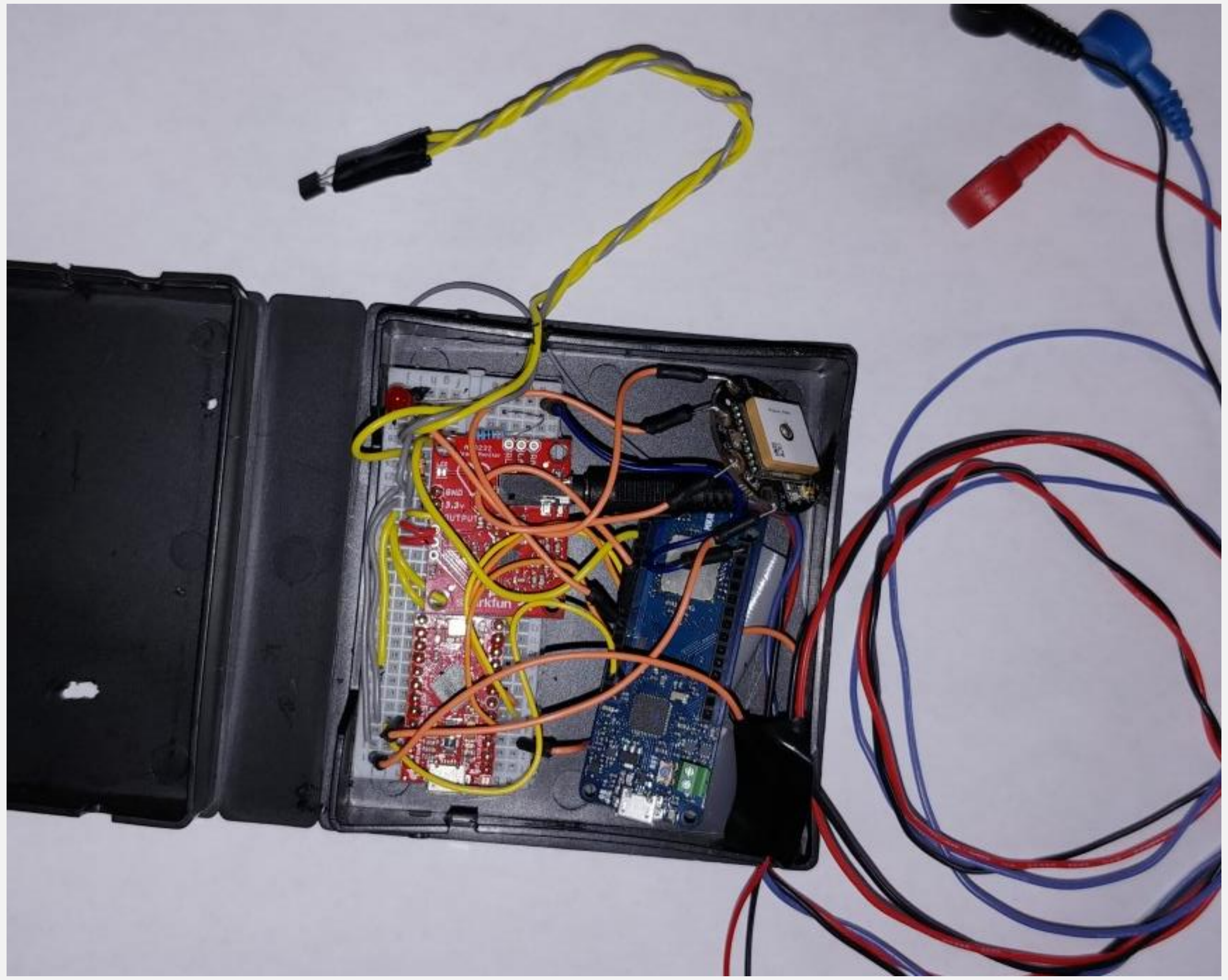
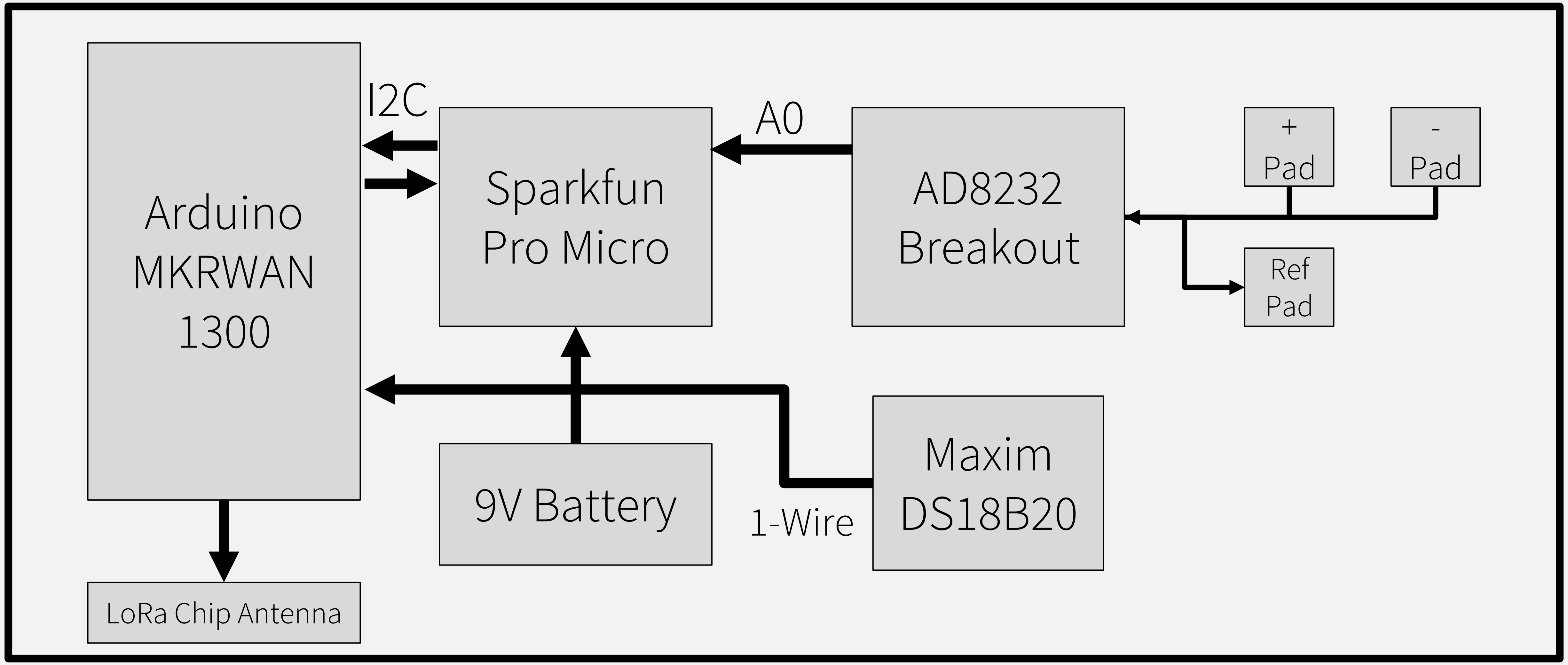
Prototype





Unit Block Diagram



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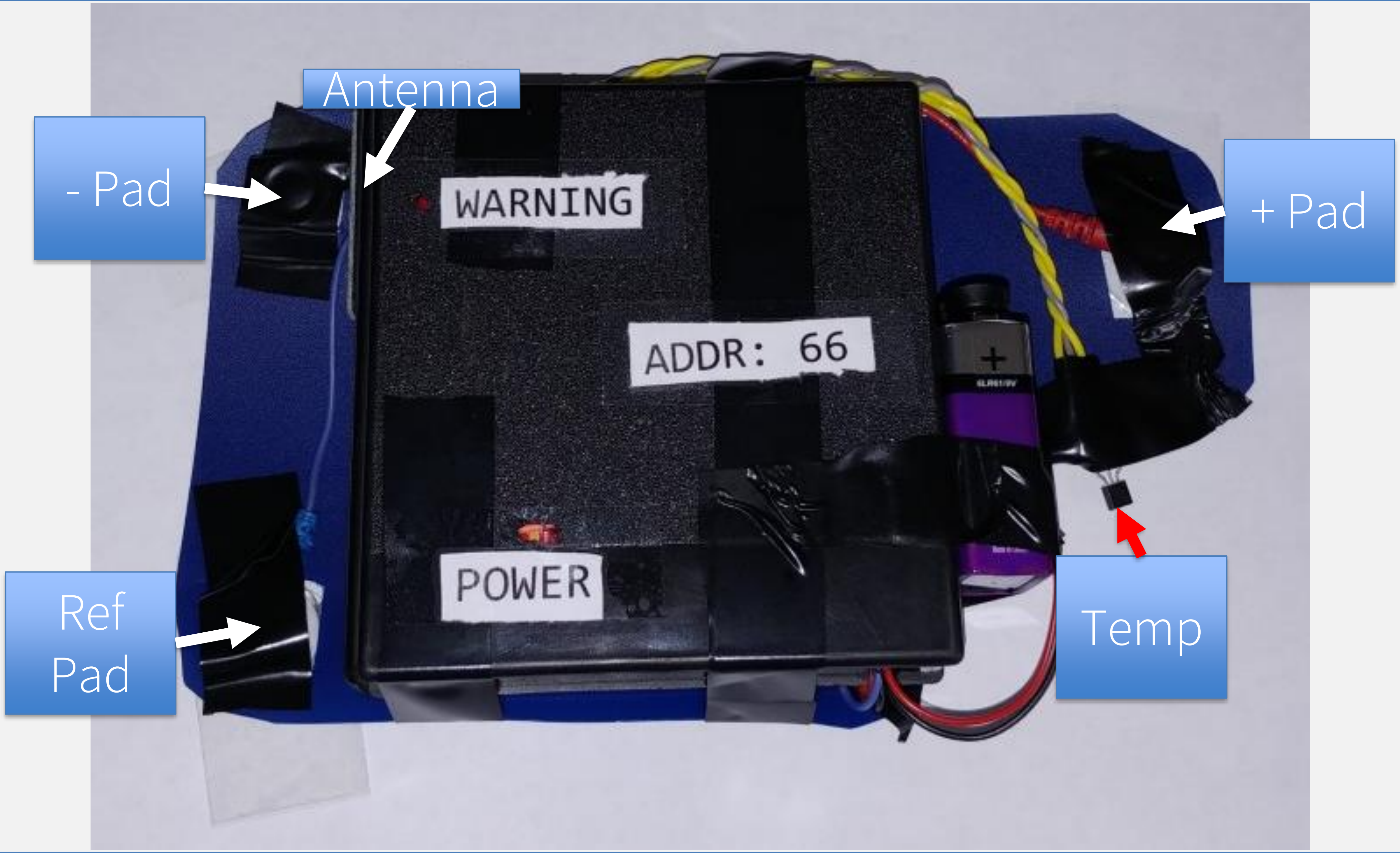
Prototype Key



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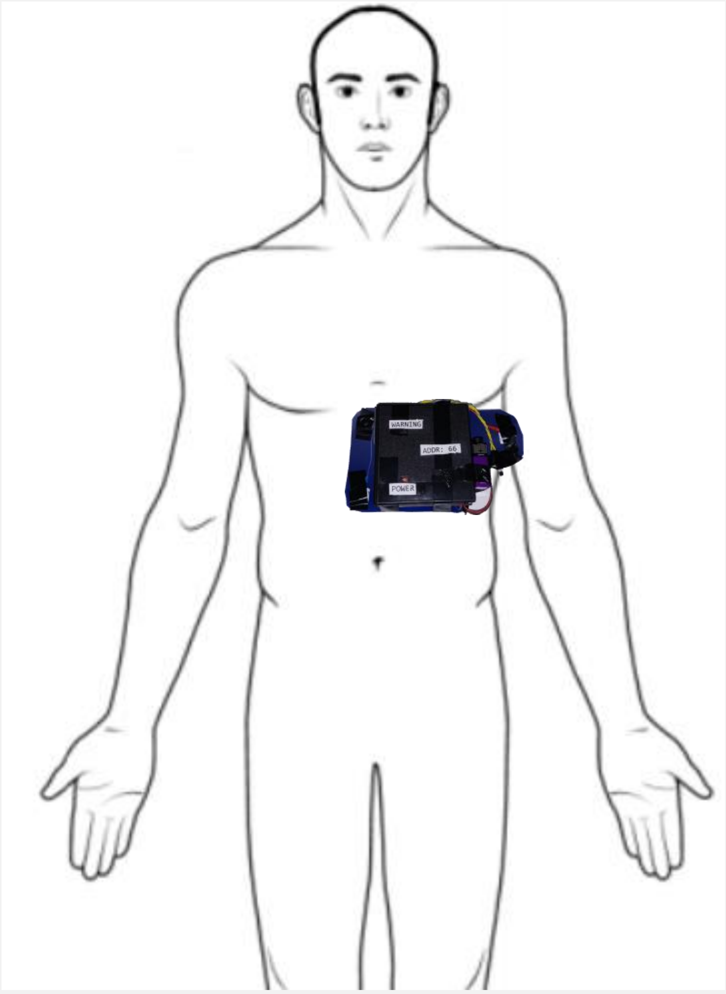
Prototype Placement



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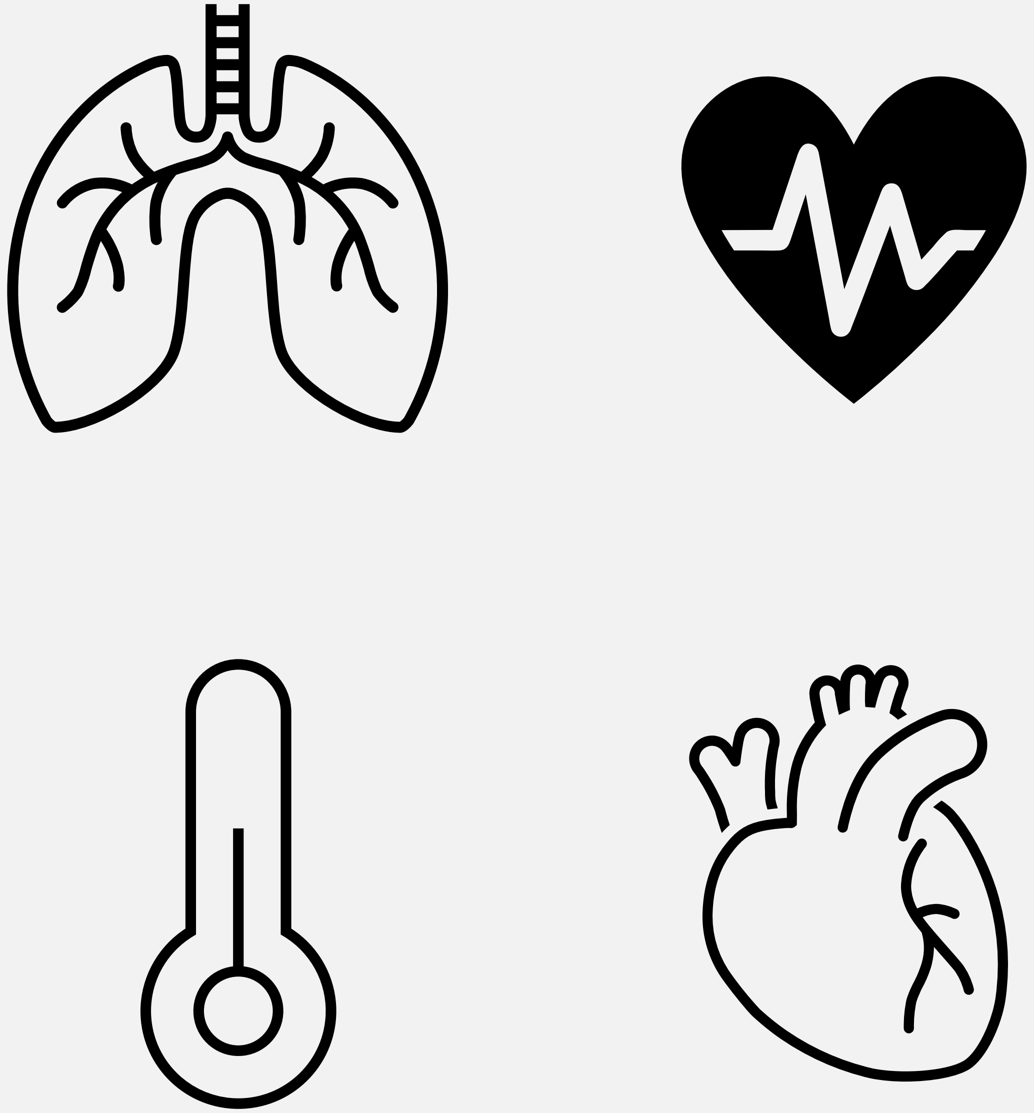
Background - Vitals

- Heart Rate
  - Shock/Injury Compensation
- Respiration Rate
  - Shock/Respiratory Distress/TBI
- Temperature
  - Hypo/Hyperthermia
- Blood Pressure
  - Shock/Massive Hemorrhage
- SpO2
  - Respiratory issues



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Vitals – Heart Rate/ECG

- AD8232
  - 3.3 V supply, nominal 170 µA
  - Integrated Right-Leg-Drive
  - Internal RFI Filtering
  - Analog output (0-3.3 V)
  - Sampled at 200 Hz, with 10 bit ADC
  - Pad connection detection

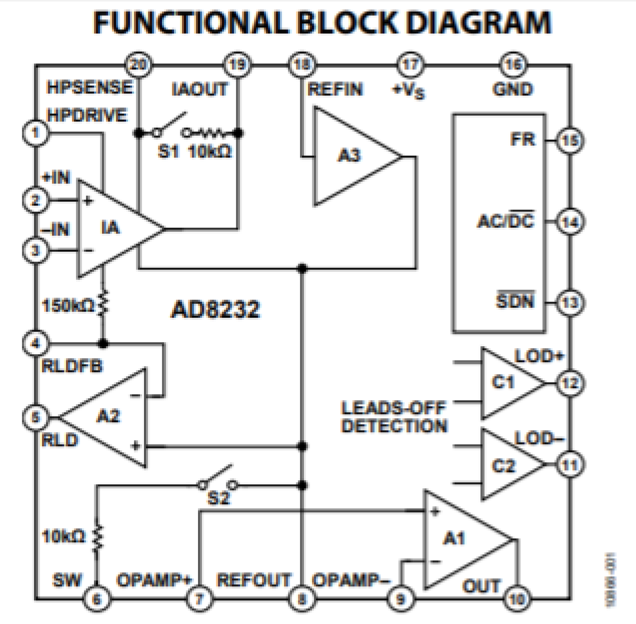
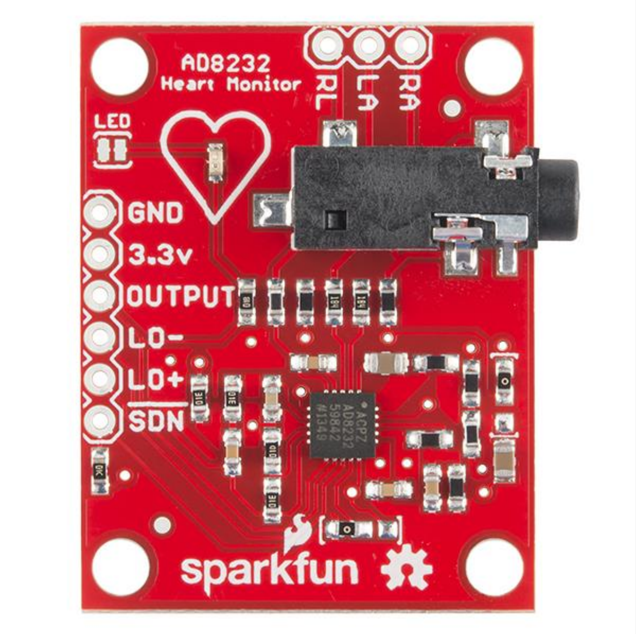


Figure 1.

Source: Analog Devices



Source: Sparkfun (CC-BY 2.0)

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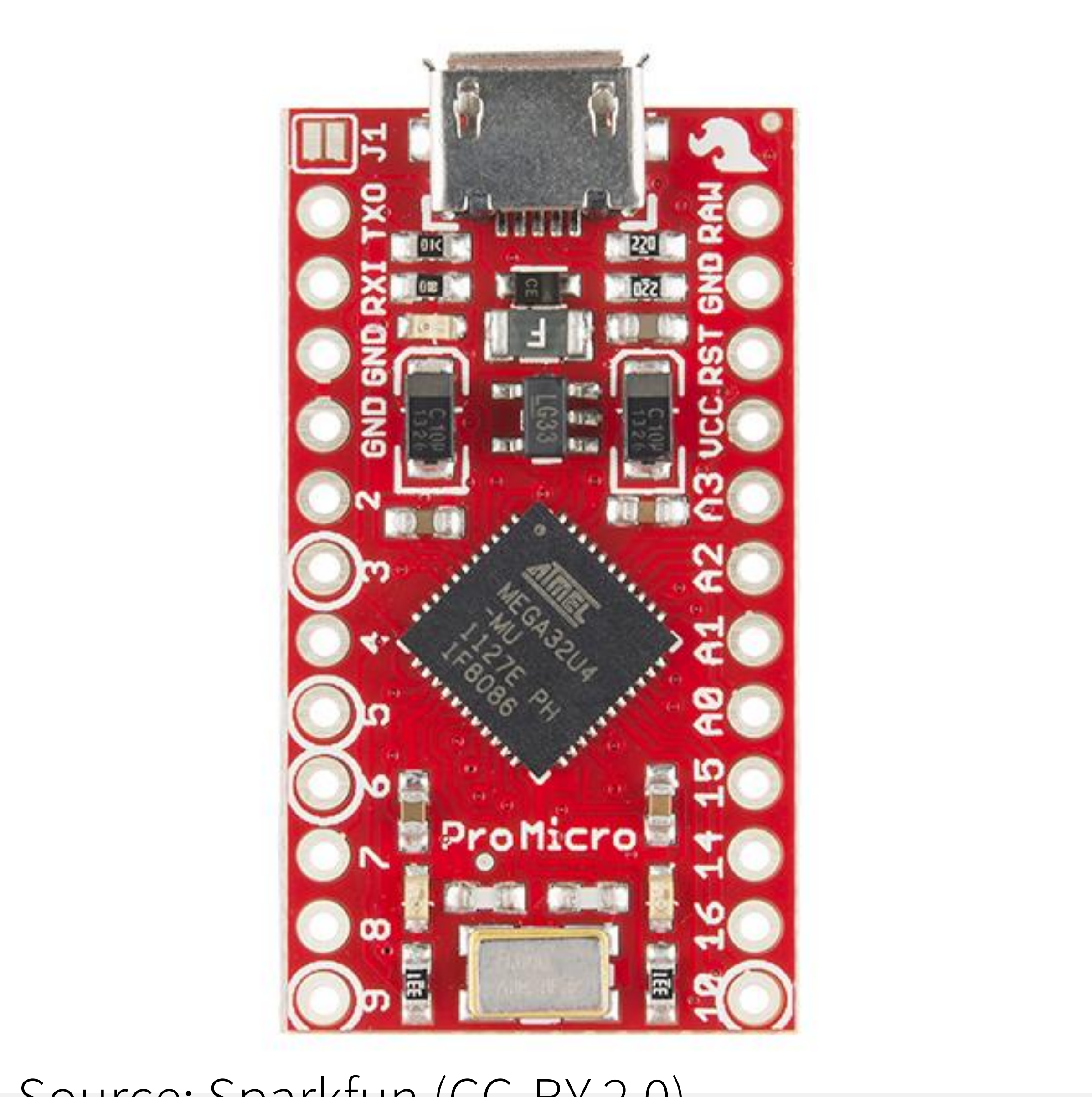
Main Signal Processing Board

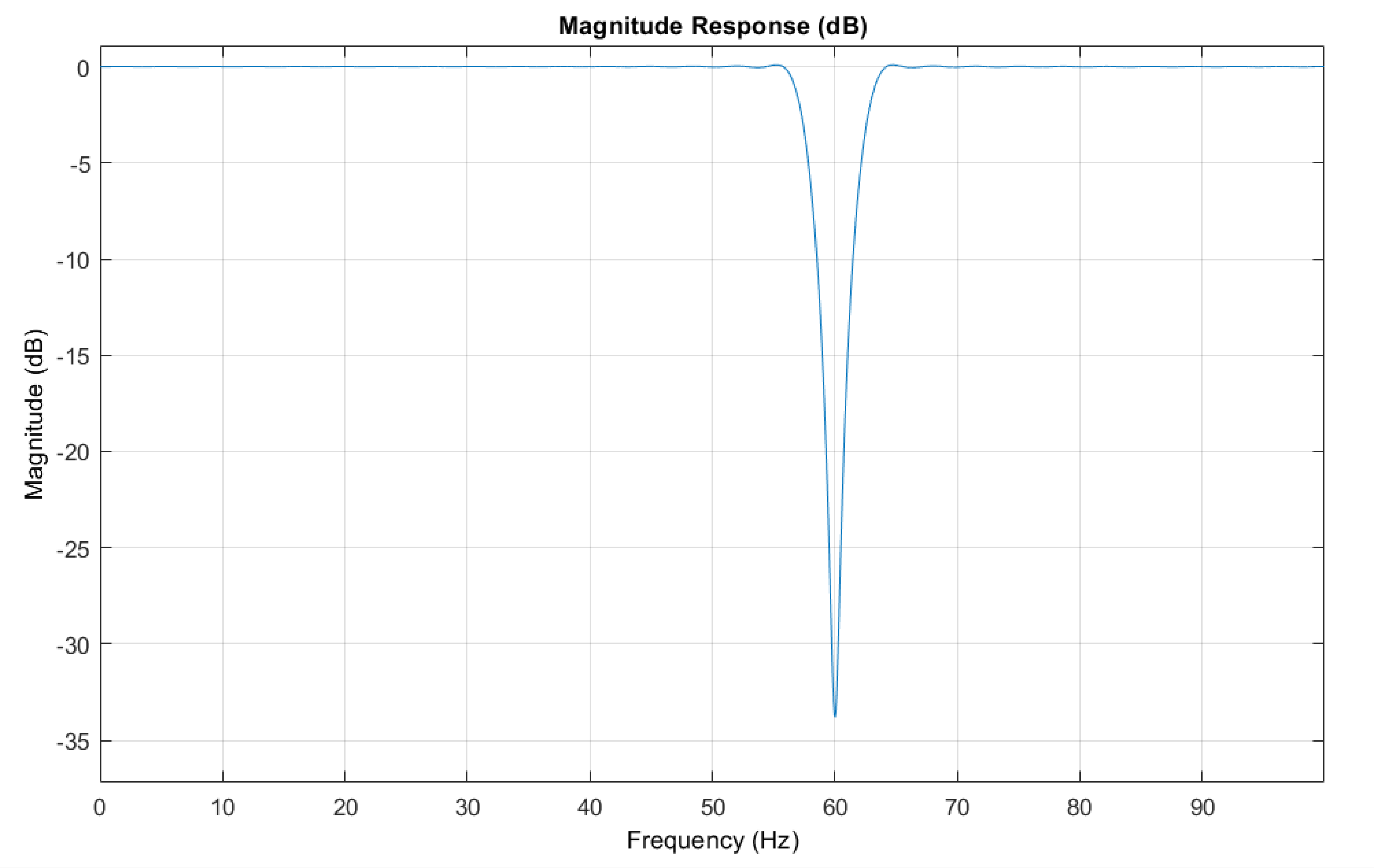
- Sparkfun Arduino Pro Micro
  - 8 mHz, 3.3 V, ATMega 32U4
  - Configured as I2C slave
  - Performs filtering, BPM, and RR calculation



Source: Sparkfun (CC-BY 2.0)

Vitals – ECG Filtering

- FIR Notch Filter 60 Hz
  - 113 Tap
  - -33 dB reduction at 60 Hz
- Simple MA Highpass
  - Removes baseline wander



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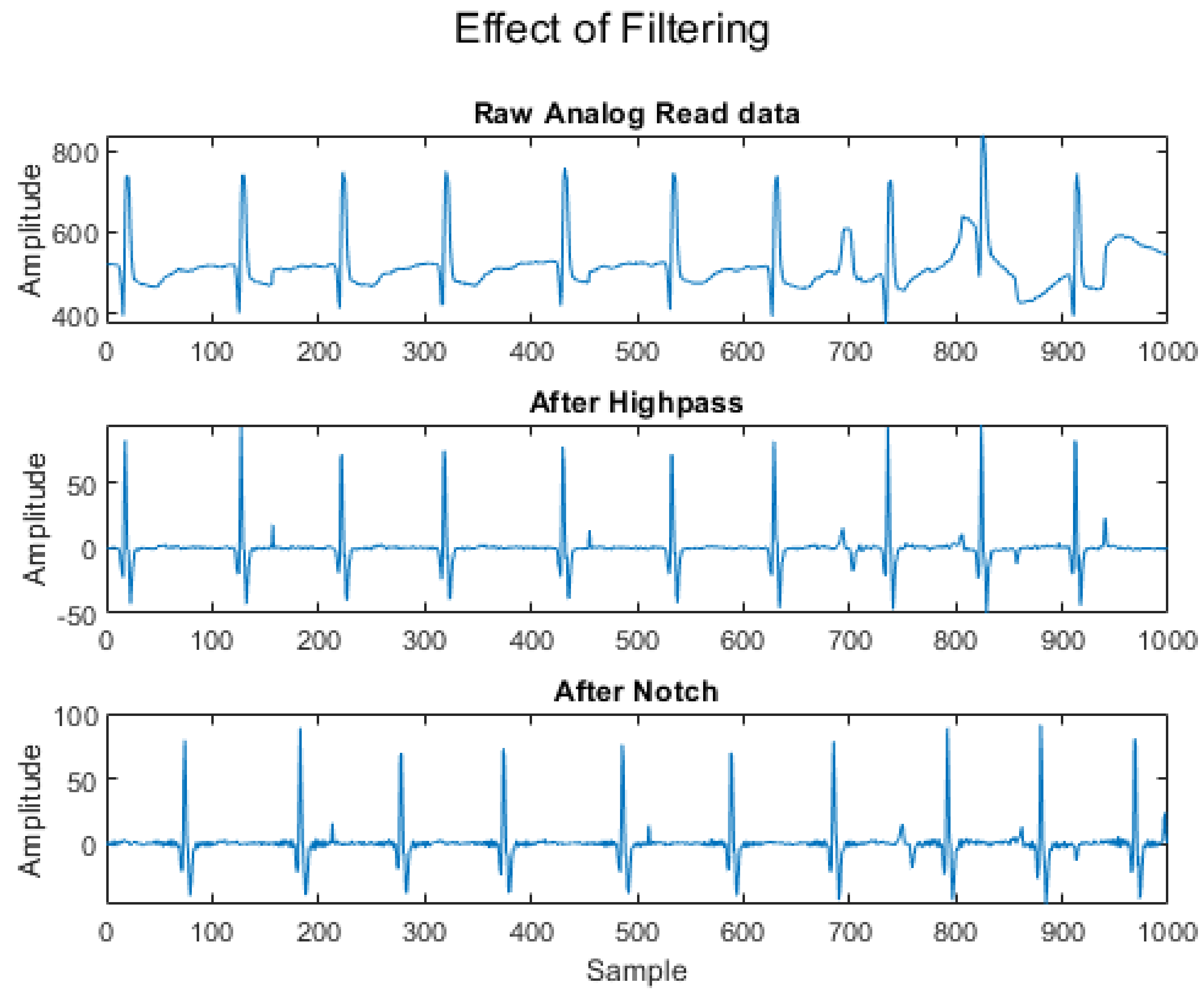
Vitals – ECG Filtering Result

- High-pass eliminated baseline wander
- Notch removed 60 Hz noise, though added ripple after QRS complex
- Note that low noise is present in this example, compared to during development and testing



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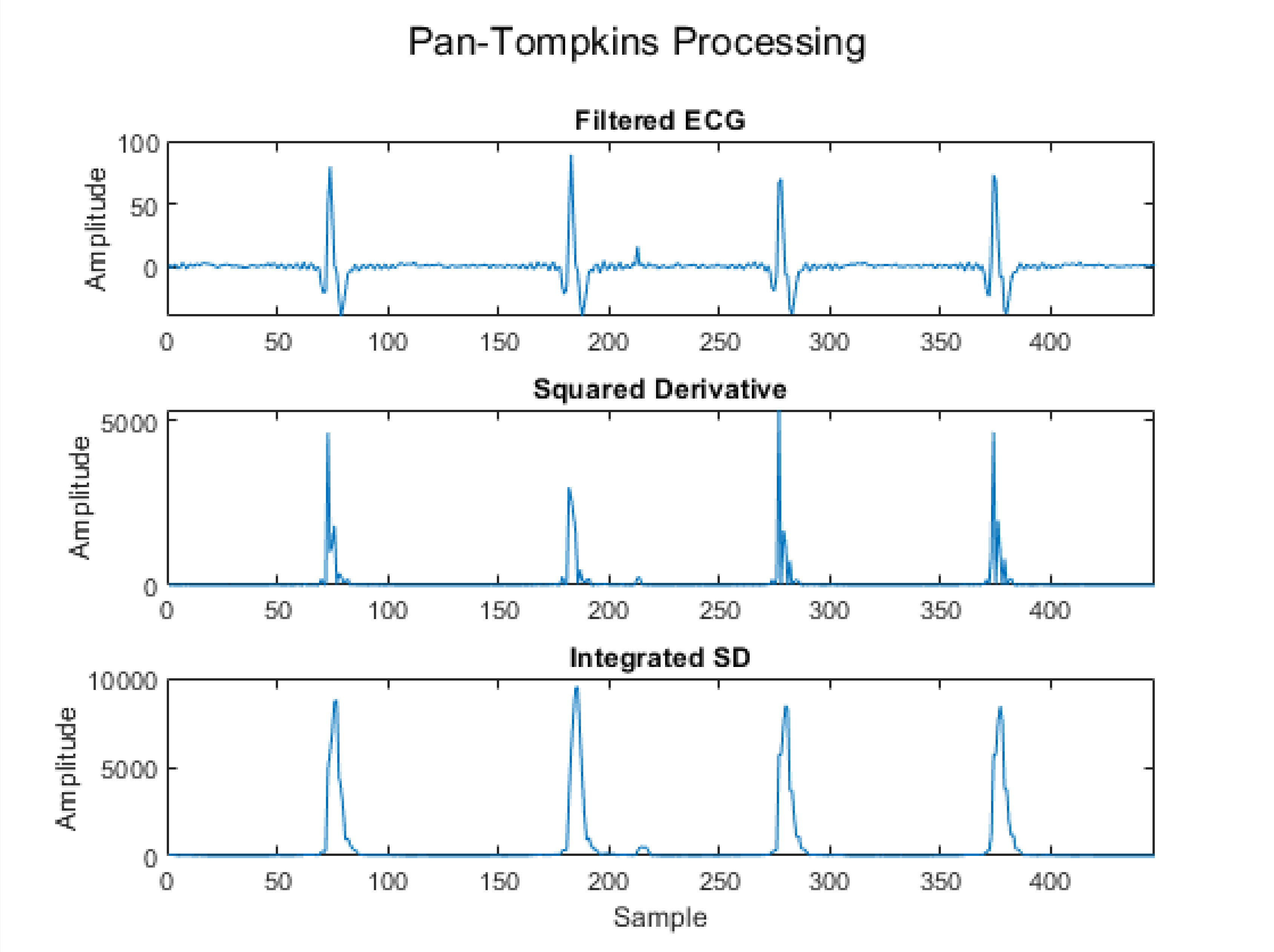
Vitals – Pan Tompkins

- Leverages quick spike in QRS complex
- Takes square of derivative
- Integrates the SQD
- Beat finding becomes trivial



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Vitals – ECG Issues

- Errors due to motion/respiration
- Inability to measure abnormal rhythms
  - Could be mitigated by sending a "snapshot"
- Potential issues with pad placement in certain scenarios/patients

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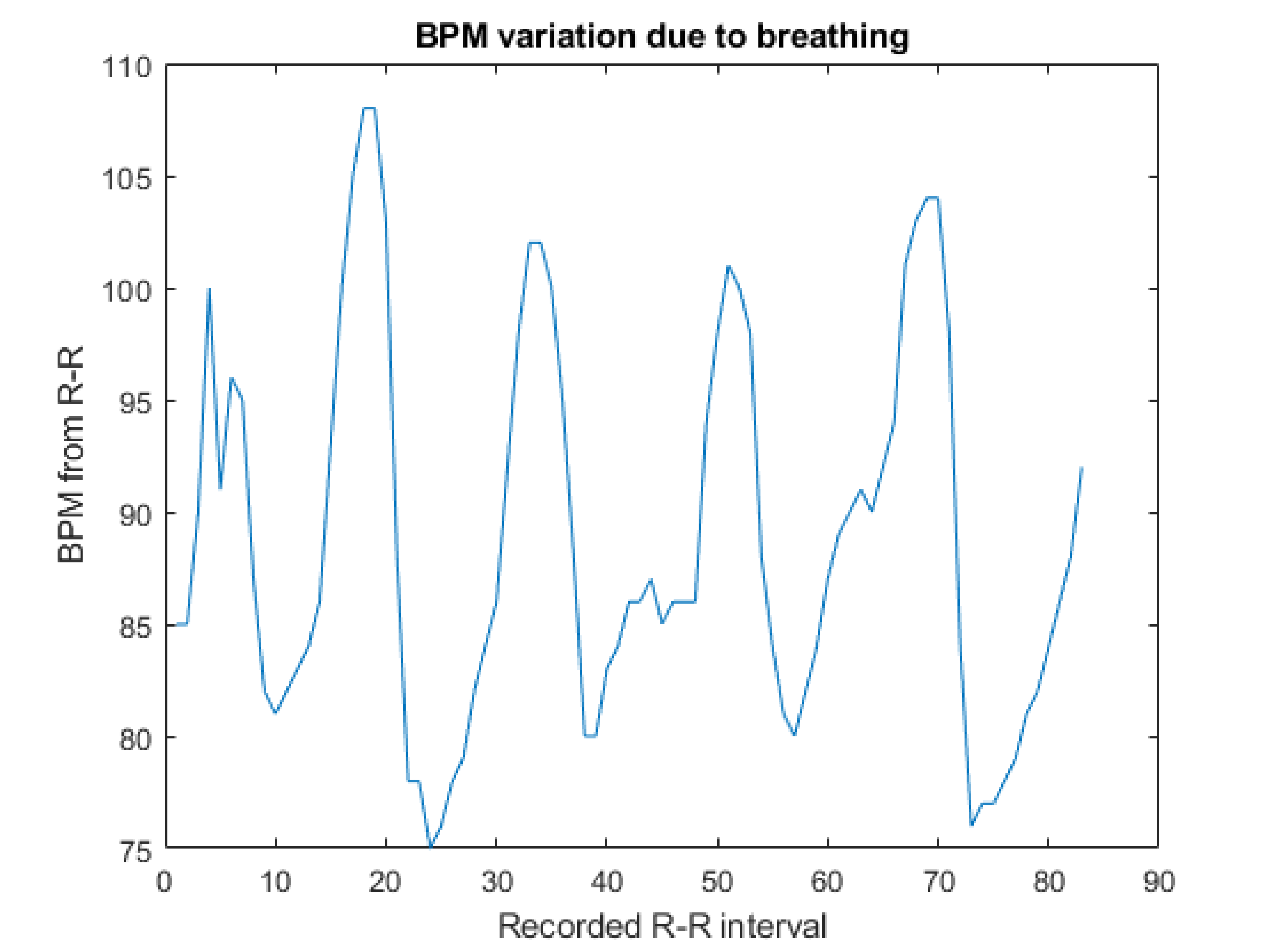
Vitals – Respiration Rate

- Estimated from change in R-R interval during inhalation and exhalation
- Find Peak, Evaluate time between peaks to approximate respiration rate



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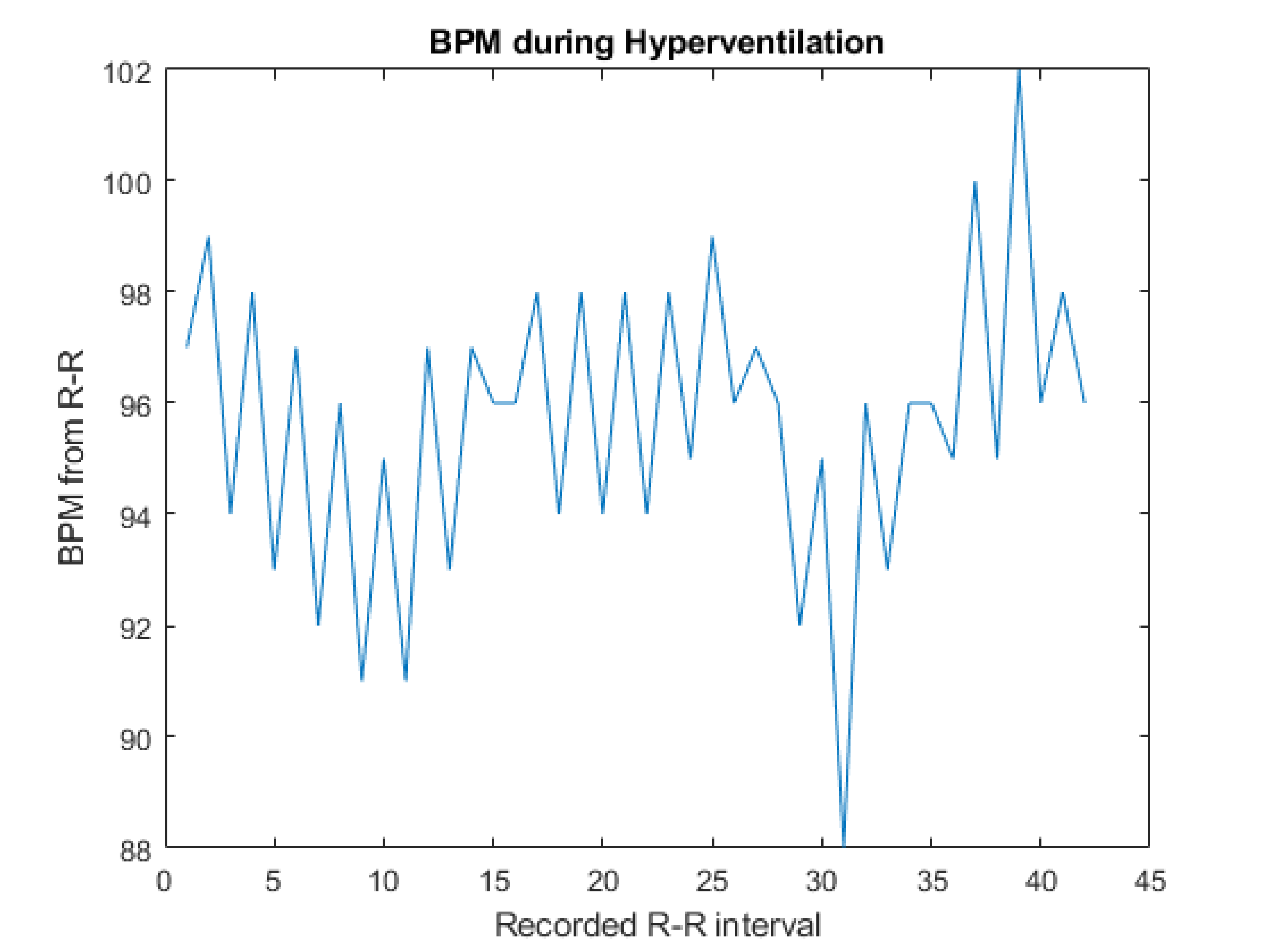
Vitals – RR issues

- Arrhythmias
- Higher resolution with higher heart rate/HRV
- May not be fast enough for hyperventilation



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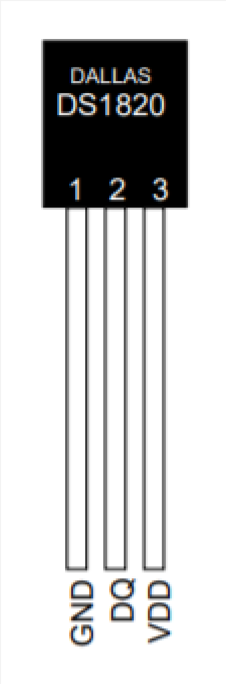
Vitals - Temperature

- Maxim (Dallas) DS18B20
  - ±0.9° F accuracy
  - Dallas 1-Wire digital output
  - 1 mA active



Source: Maxim Integrated

Vitals – Temperature Theory

- Skin temperature and core temperature are related (Lenhardt, Sessler 2006)
- Skin in/near the armpit is close to core temperature due to blood flow

Vitals – Temp Issues

- 1-Wire interface/ADC operation is blocking, and takes time
- Interfered with ECG timing
  - Moved to MKRWAN 1300

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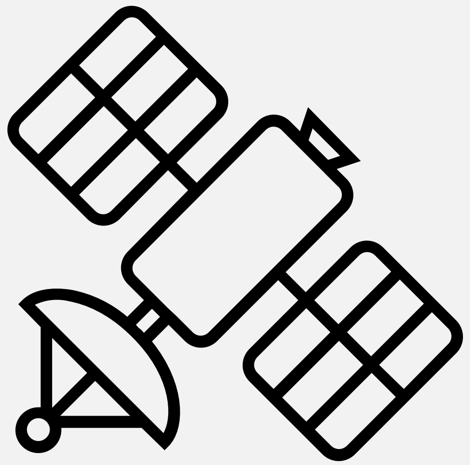
GPS Location

- GTOP PA6H
  - 66 channel
  - 25 mA Acquisition, 20 mA Tracking
  - <10 m error
  - Serial NMEA strings



GPS Issues

- Not useful in indoor/some urban scenarios
- High power usage
  - Limits possible uptime of device

Wireless - LoRa

- "Long Range"
  - Nominal 10 km range
  - Low Data rate/bandwidth
  - 915 mHz ISM band
- Arduino MKRWAN 1300
  - SAMD21
  - Murata CMWX1ZZABZ

Source: Arduino

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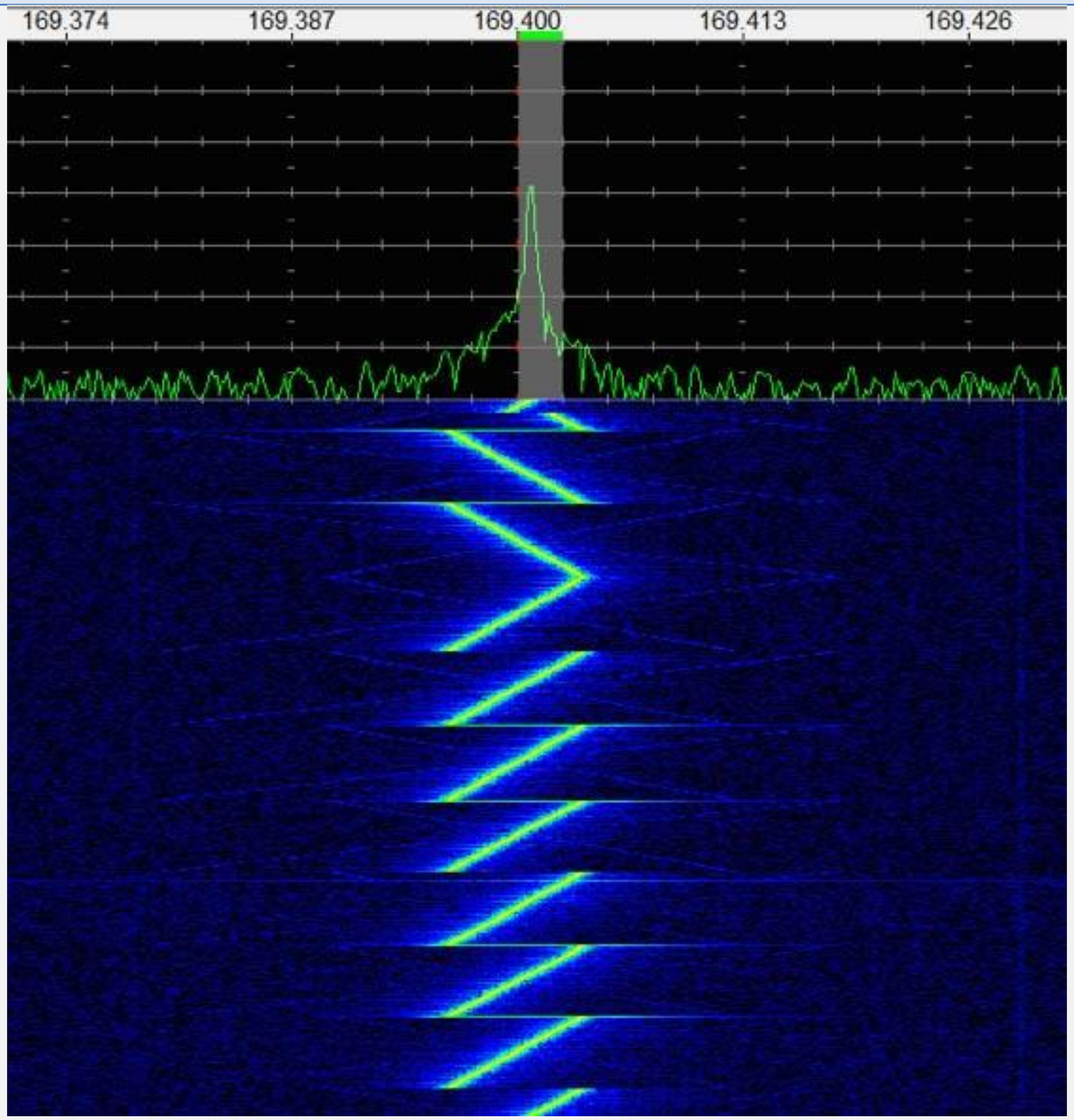
Wireless – LoRa limitations

- Best performance with LoS
- Collisions
- Interference
- Limited Data Rate (5500 bps)
- Practical range under 1 Km with obstructions
  - Could be improved via use of better antenna systems, or increased spreading factor



Source: SBR Labs (CC-BY-SA 2.0)

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Wireless – Data Format

- 1 byte address
- 1 byte BPM
- 1 byte RR
- 2 bytes Temp
- 8 bytes Location
- Converted to Byte Array, and XOR enciphered

5C2433445422334 46FAE8A2F1855764B7D356B70966284

Wireless Transmission Scheme

- Send latest recorded data randomly between 5 and 10 seconds from last
  - Decreases probability of two similarly started units constantly colliding
  - Allows for multiple devices on one frequency

Wireless – Hub/Decoding

- Arduino MKRWAN1300
  - Monitors frequency
  - If address of packet within whitelist, data is XOR deciphered
  - Parsed into human readable USB serial string

```
Data: 482E334454223344D81677182557643F22511678966284
ADDR: 66 BPM: 89, RR: 12, TEMP: 69, LAT: 42[redacted]LON: -70[redacted] with RSSI -41
Data: 482E334454223344D81677182557643F22511678966284
ADDR: 66 BPM: 89, RR: 12, TEMP: 69, LAT: 42[redacted] LON: -70[redacted] with RSSI -41
Data: 702B334454223344DEE22D88255764CBA9EFF78966284
ADDR: 66 BPM: 97, RR: 9, TEMP: 69, LAT: 42 [redacted] LON: -70.[redacted] with RSSI -41
Data: 442B334454223344DEE22D88255764CBA9EFF78966284
ADDR: 66 BPM: 85, RR: 9, TEMP: 69, LAT: 42 [redacted], LON: -70.[redacted] with RSSI -41
Data: 442A334454223344DEE22D88255764CBA9EFF78966284
ADDR: 66 BPM: 85, RR: 8, TEMP: 69, LAT: 42.[redacted], LON: -70.[redacted] with RSSI -41
Data: 492A334454223344DEE22D88255764CBA9EFF78966284
ADDR: 66 BPM: 88, RR: 8, TEMP: 69, LAT: 42.[redacted], LON: -70.[redacted] with RSSI -41
Data: 763B334454223344584AF8FD55576477A5104C7B966284
ADDR: 66 BPM: 103, RR: 25, TEMP: 69, LAT: 42.[redacted], LON: -7[redacted]2 with RSSI -43
Data: 722F334454223344B7634878165576428B92BF4E966284
ADDR: 66 BPM: 99, RR: 13, TEMP: 69, LAT: 42[redacted] LON: -70[redacted] with RSSI -42
Data: 4B2A334454223344FBEED4671255764C74C88944D966284
ADDR: 66 BPM: 90, RR: 8, TEMP: 69, LAT: 42[redacted] LON: -70.[redacted] with RSSI -42
Data: 4E2A334454223344B0A537314557647748E784F966284
ADDR: 66 BPM: 95, RR: 8, TEMP: 69, LAT: 42[redacted], LON: -70.[redacted] with RSSI -42
```

Wireless – Python Logging

- Data parsed again, and stored in CSV with timestamps
- Warnings displayed in console if normal ranges exceeded

```
Addr: 66, 79, 12, 71
RESPWARN: 66 may be Bradypneic
Addr: 66, 75, 4, 71
RESPWARN: 66 may be Bradypneic
Addr: 66, 95, 4, 71
Addr: 66, 97, 7, 71
Addr: 66, 87, 10, 71
Addr: 66, 86, 8, 71
Addr: 66, 83, 8, 71
HEARTWARN: 66 may be Bradycardic
Addr: 66, 39, 9, 71
RESPWARN: 66 may be Hyperventilating
Addr: 66, 76, 37, 71
HEARTWARN: 66 may be Tachycardic
Addr: 66, 129, 10, 71
HEARTWARN: 66 may be Tachycardic
Addr: 66, 126, 15, 71
HEARTWARN: 66 may be Tachycardic
RESPWARN: 66 may be Hyperventilating
Addr: 66, 223, 49, 71
RESPWARN: 66 may be Hyperventilating
Addr: 66, 70, 24, 71
RESPWARN: 66 may be Hyperventilating
Addr: 66, 75, 24, 71
RESPWARN: 66 may be Hyperventilating
Addr: 66, 76, 34, 71
RESPWARN: 66 may be Hyperventilating
Addr: 66, 64, 23, 71
RESPWARN: 66 may be Hyperventilating
Addr: 66, 76, 27, 71
HEARTWARN: 66 may be Bradycardic
Addr: 66, 59, 19, 71
RESPWARN: 66 may be Hyperventilating
Addr: 66, 70, 28, 71
HEARTWARN: 66 may be Bradycardic
RESPWARN: 66 may be Hyperventilating
Addr: 66, 51, 25, 71
HEARTWARN: 66 may be Tachycardic
RESPWARN: 66 may be Hyperventilating
Addr: 66, 118, 25, 71
Addr: 66, 86, 7, 71
Addr: 66, 75, 10, 71
```

04:56.3	83	9	88	0	0	0	0
05:01.3	81	10	88	42	-70	0	0
05:06.3	82	12	88	42	-70	0	0
05:11.3	83	13	88	42	-70	0	0
05:16.3	86	75	88	42	-70	0	1
05:21.3	84	11	88	42	-70	0	0
05:26.3	74	11	88	42	-70	0	0
05:31.3	81	8	88	42	-70	0	0
05:36.3	64	8	88	42	-70	0	0
05:41.3	64	7	89	4	-70	0	0
05:46.3	120	10	90	42	-70	1	0
05:51.3	120	11	90	42	-70	1	0
05:56.3	57	23	90	42	-70	2	1
06:01.3	114	7	90	42	-70	1	0
06:06.3	64	10	90	42	-70	0	0
06:11.3	117	59	90	42	-70	1	1
06:16.3	108	11	90	42	-70	1	0
06:21.3	224	15	90	42	-70	1	0
06:26.3	100	16	90	42	-70	0	0
06:31.3	108	16	90	42	-70	1	0
06:36.3	106	8	90	42	-70	1	0
06:41.3	114	10	90	42	-70	1	0
06:46.3	113	22	90	42	-70	1	1
06:51.3	109	9	90	42	-70	1	0
06:56.3	110	22	90	42	-70	1	1
07:01.3	35	15	90	42	-70	2	0
07:06.3	106	36	90	42	-70	1	1
07:11.3	231	35	90	42	-70	1	1

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Prototype Cost

Component	MSRP	Quantity	
MKRWAN 1300	$40.30	2	
Sparkfun Pro Micro 3v3	$17.95	1	
AD8232 Breakout	$19.95	1	
Electrode Cable	$4.95	1	
Ag-AgCl Electrodes	$8 ($2.67)	1	
DS18B20 Temp Sensor	$3.95	1	
PA6H GPS	$40	1	
		TOTAL	~$170

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Future Work/Improvements

- Improve robustness of BPM and RR calculation
- Cost Reduction
- Build multiple devices and evaluate
- Add blood pressure estimation
  - May be possible via use of PPG sensor and calculation of Pulse Wave Velocity
- Custom one-board PCB
- Use alternative MCU with standalone LoRa unit
- Develop GUI

Issues Encountered During Project

- Time Management & Other Workload
- Sensor decisions
- High Speed vs Low Speed
- Overfocusing on smaller concerns
- Team size of one

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Summary/Conclusion

- A functioning prototype wearable was designed and constructed, and could send heart rate, respiration rate, and body temperature wirelessly to a control PC.
- The efficacy of the prototype in a practical scenario has yet to be evaluated, but shows promise.

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Thank You

Special Thanks to Dr MD Shaad Mahmud, and the UNH RSL, for support and guidance

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