An Intelligent Mattress for Diagnosis of Sleep Apnea

BY:

GERMAN SHEIN (48610)

SANKAR SATHYANARAYANAN (48966)

ADVISORS: DR. MICHEL BERNARD PASQUIER AND DR. ASSIM SAGAHYROON

Outline

- Sleep apnea
- Existing home medical systems
- Our solution
- Implementation
- Testing
- Cost estimation
- Impact of the project

Sleep apnea

- Breathing is paused or becomes shallow during sleep.
- Types:
  - Obstructive Sleep Apnea (OSA) – blocked upper airway.
  - Central Sleep Apnea (CSA) – no effort to breathe.
  - Mixed.
- ~42 million of USA adults suffer from various Sleep-Disordered Breathing illnesses.

Diagnosis

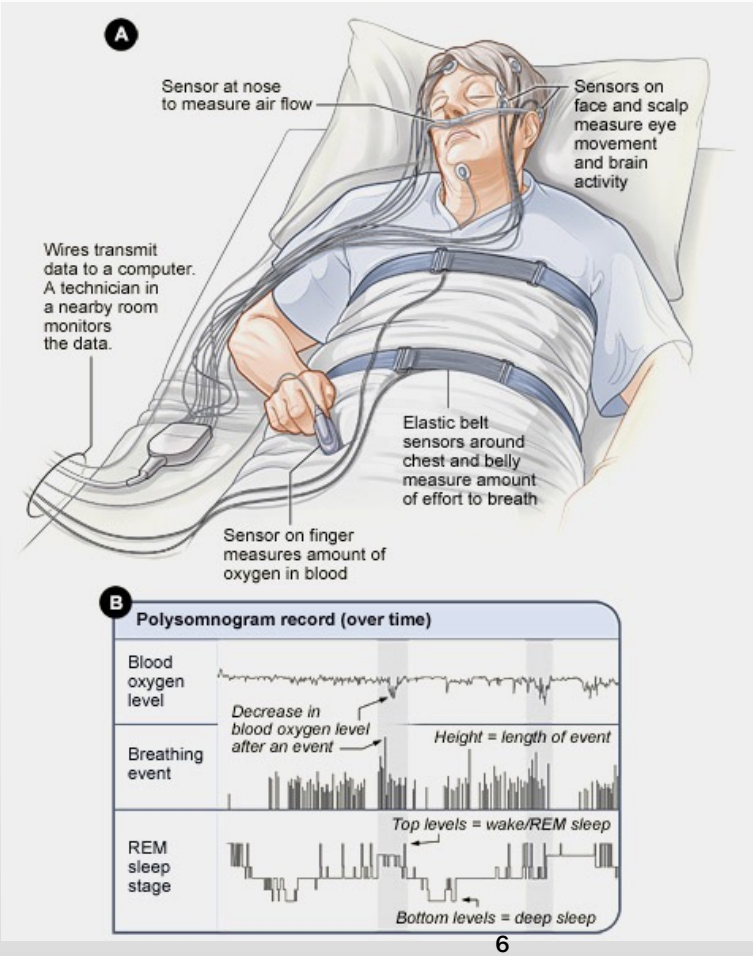
- Pulse oximetry
- Polysomnography
- Electrocardiogram
- Detecting individual symptoms

Pulse oximetry

- Measures oxygen saturation
- Good indicator: no breathing => lower saturation
- Advantages:
  - Can be used at home
  - Non-obtrusive and non-invasive
- Disadvantage: questionable diagnosis precision

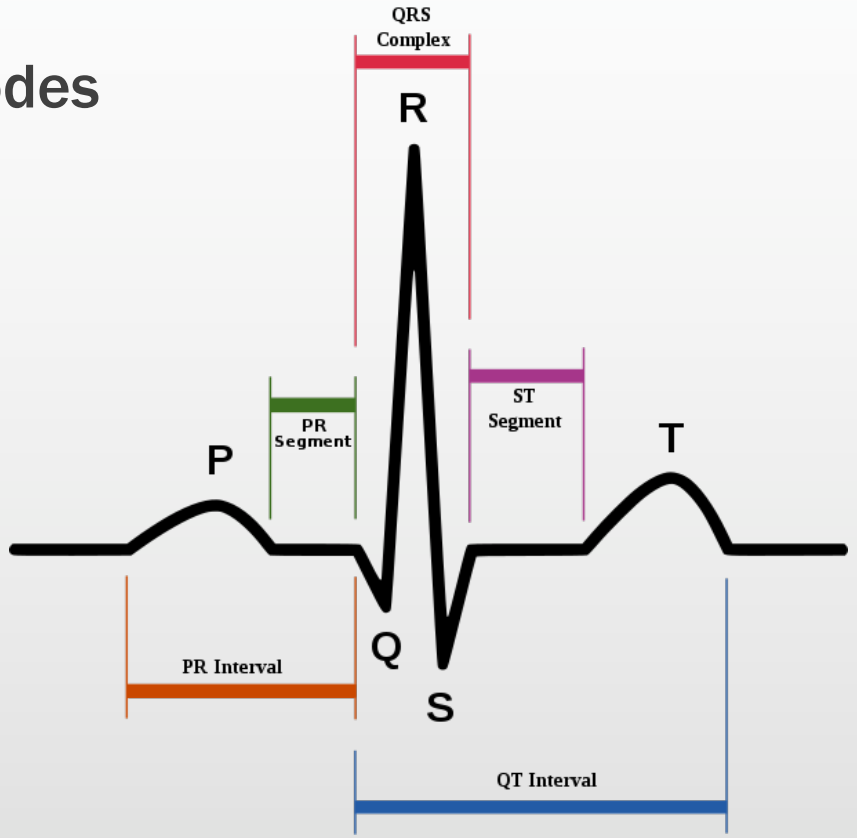
Polysomnography

- Complex sleep study involving multiple measurements:
  - Electroencephalography (EEG)
  - Electrooculography (EOG)
  - Electromyography (EMG)
  - Electrocardiography (ECG)
- Advantages:
  - Highly precise diagnostic tool
  - Can produce multiple types of sleep disorders
- Disadvantages :
  - Extremely obtrusive
  - Expensive to replicate
  - Requires the observation by a medical doctor



Electrocardiogram

- Represents electrical activity of the heart
- Increased amplitude during apnea episodes
- Advantage: precise diagnosis
- Disadvantage: obtrusive



Detecting individual symptoms

- Symptoms of interest
  - Heart rate increase
  - Stopping of lungs' movement
  - Snoring (OSA) or shallow breathing (CSA)
- Advantages:
  - Easy to implement
  - Arguably non-obtrusive
- Disadvantages:
  - Each symptom alone does not signify sleep apnea
  - Not all risk factors and symptoms can be accounted for

Why detecting individual symptoms?

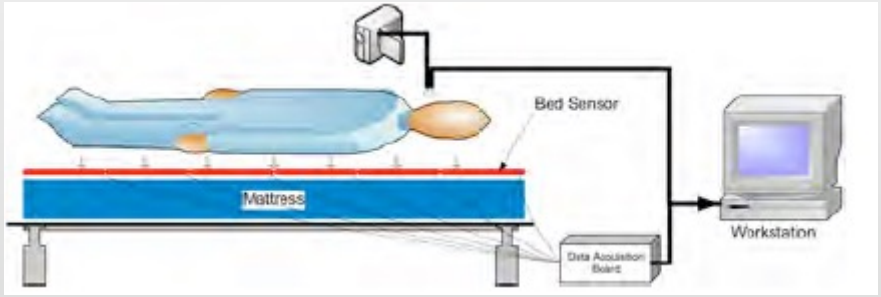
- Non-obtrusiveness
- Potentially help the medical research
- Can be modified for other purposes

Existing home medical systems

- Cue (https://cue.me/)
- EagleEyeMed EagleX (http://eagleyemed.com/eaglex/)
- Intelligent Bed Sensor by University of Victoria
- Sleep apnea mobile applications developed in AUS

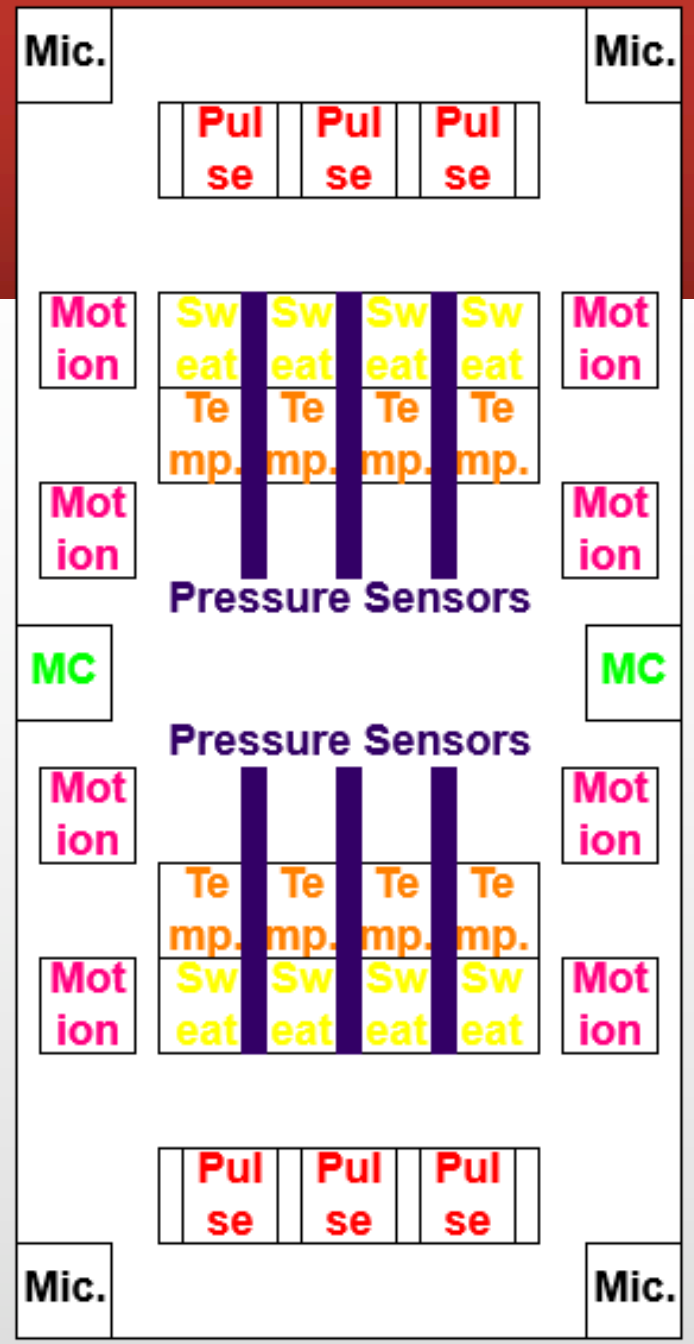
Intelligent Bed Sensor by University of Victoria

- 144 optical pressure sensors
- Detects sleep movements and sleep apnea
- Results are generally good…
- … but standard deviation is around 25 %



Our solution

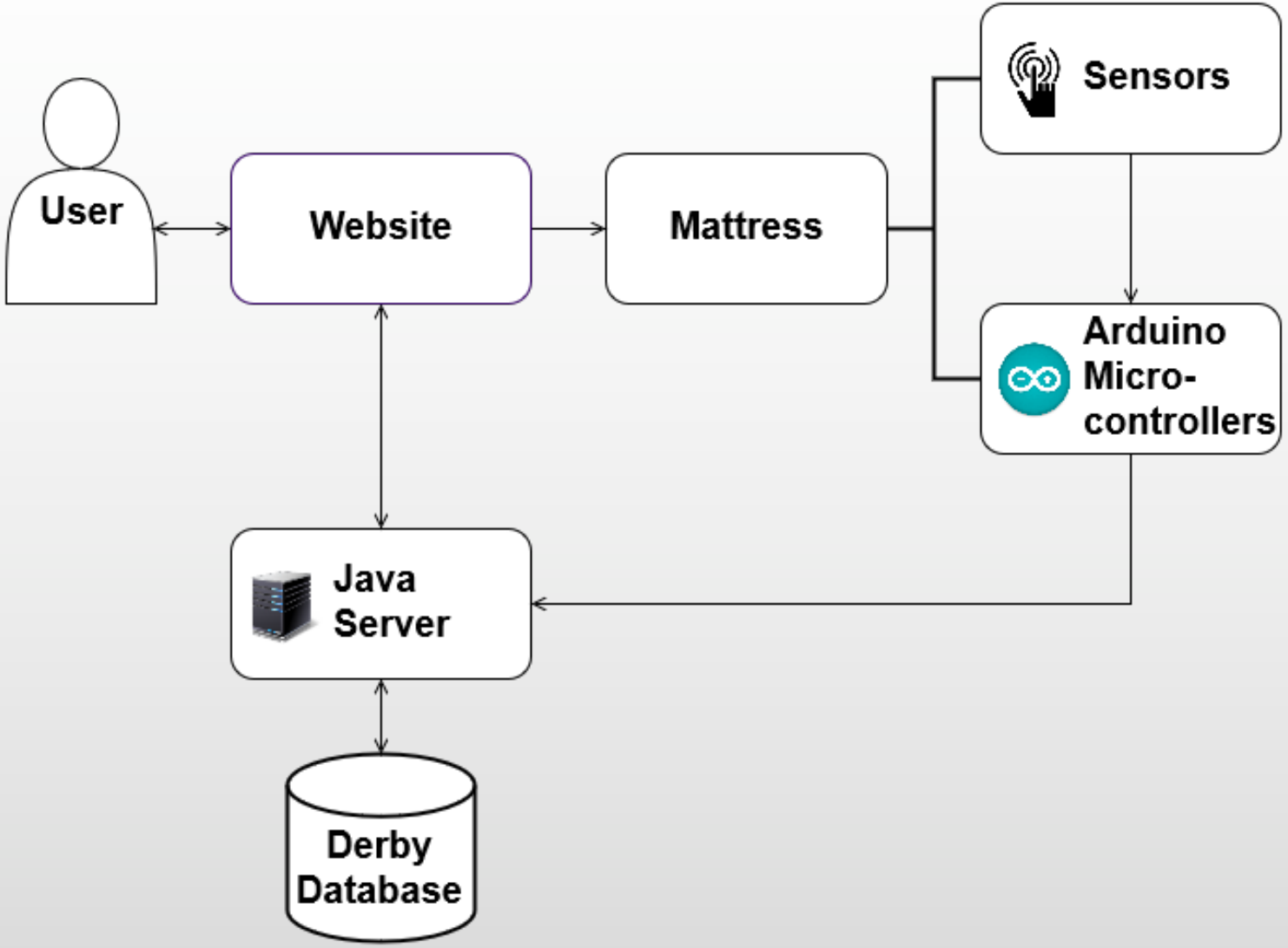
- Mattress as a sensor:
  - Heart rate (6) (placed on a prop)
  - Breathing/snoring sound (4)
  - Lungs' and diaphragm's pressure (6)
  - Body temperature (8)
  - Sweating (8)
  - Motion (8)
- Microcontrollers gather data
- Non-obtrusive AND non-invasive
- Individual symptoms are detected
- Patients' database
- Assess risk of sleep apnea



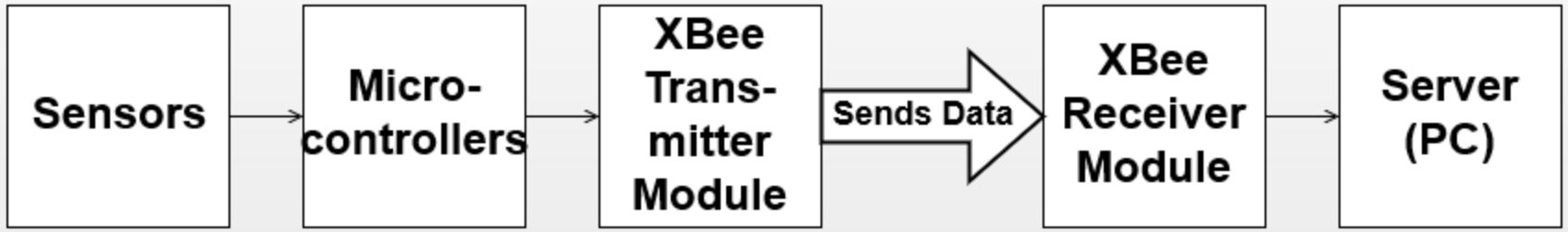
How does it work?

- User logs through a website in and lies on a mattress
- Sensory data is sent to the server
- Sleep stages are determined
- Detecting individual symptoms
- System compares results with the others
- Results are stored and diagnosis is presented through a website.

System architecture



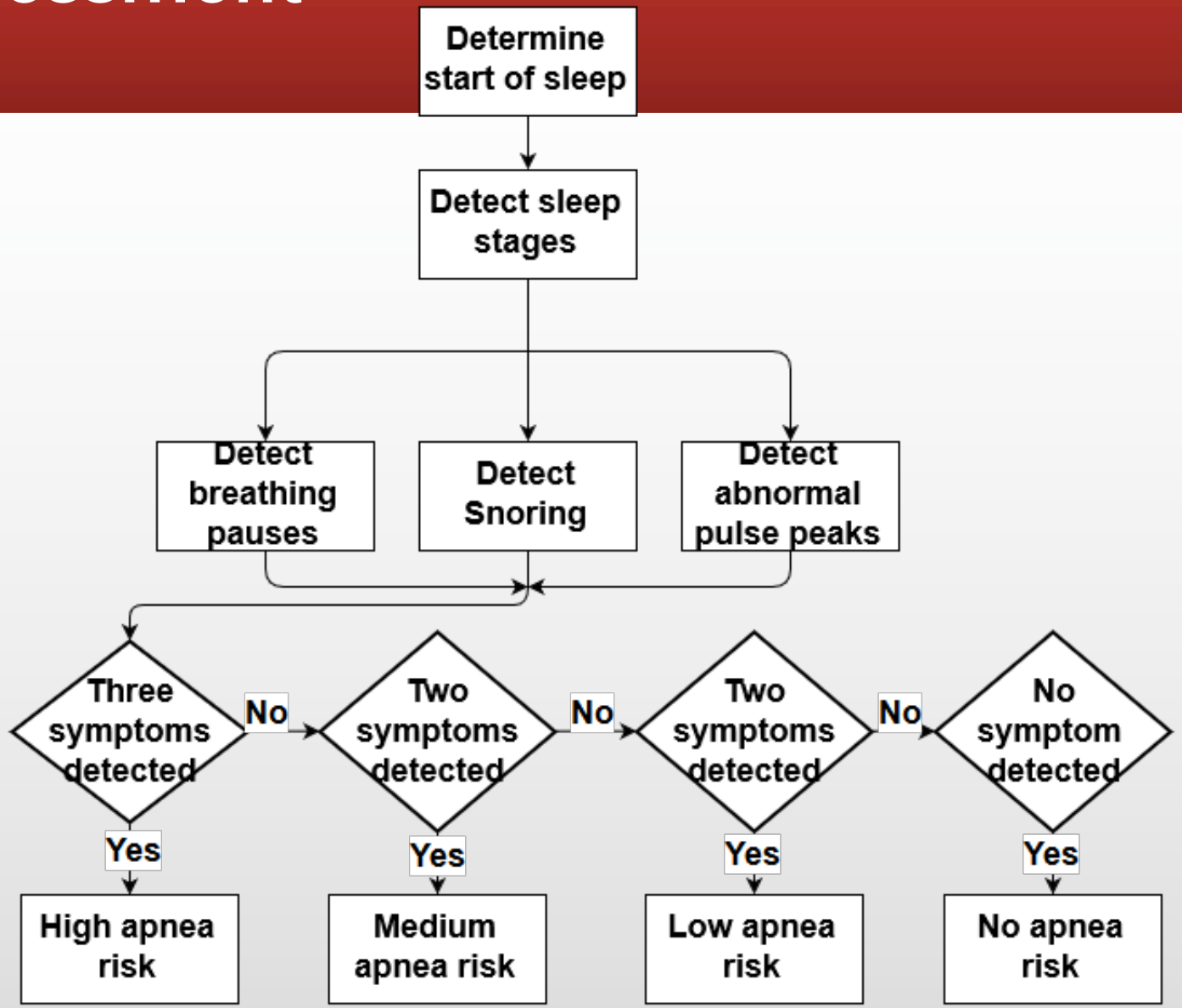
Data flow


Sensors
Micro-controllers
XBee Trans-mitter Module
Sends Data
XBee Receiver Module
Server (PC)

Diagnostic criteria

- Detect NREM and REM sleep stages
- At least 5 apnea episodes within an hour are needed for diagnosis
- Find abnormalities:
  - Pulse is larger than 80 BPM (NREM stage) or 87 BPM (REM stage)
  - Pressure force applied on mattress by lungs is less than 0.1 N
  - Sound level of breathing is below 20 dB (CSA) or larger than 70 dB (OSA)

Risk assessment



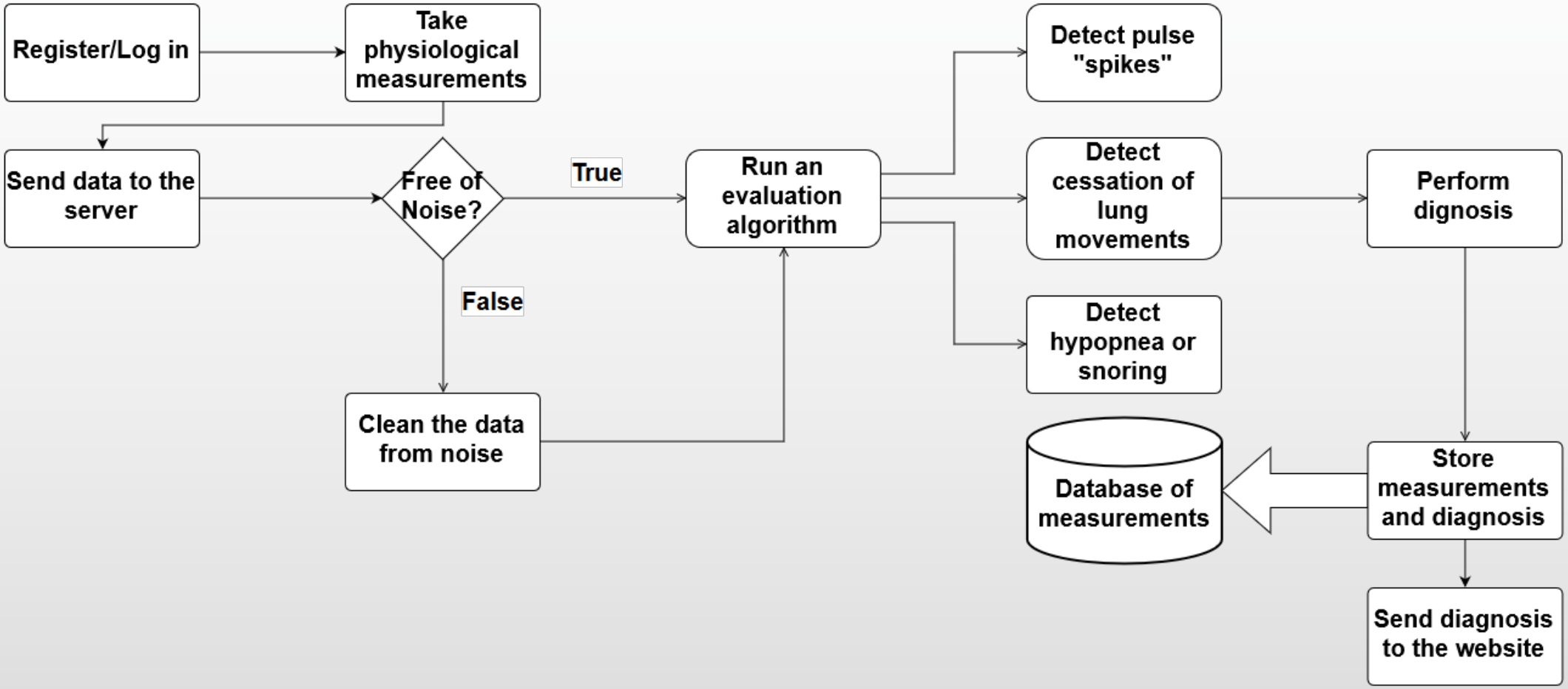
Database schema

- Tables for each sensory reading
- Tables of users
- Tables of results

Assumptions

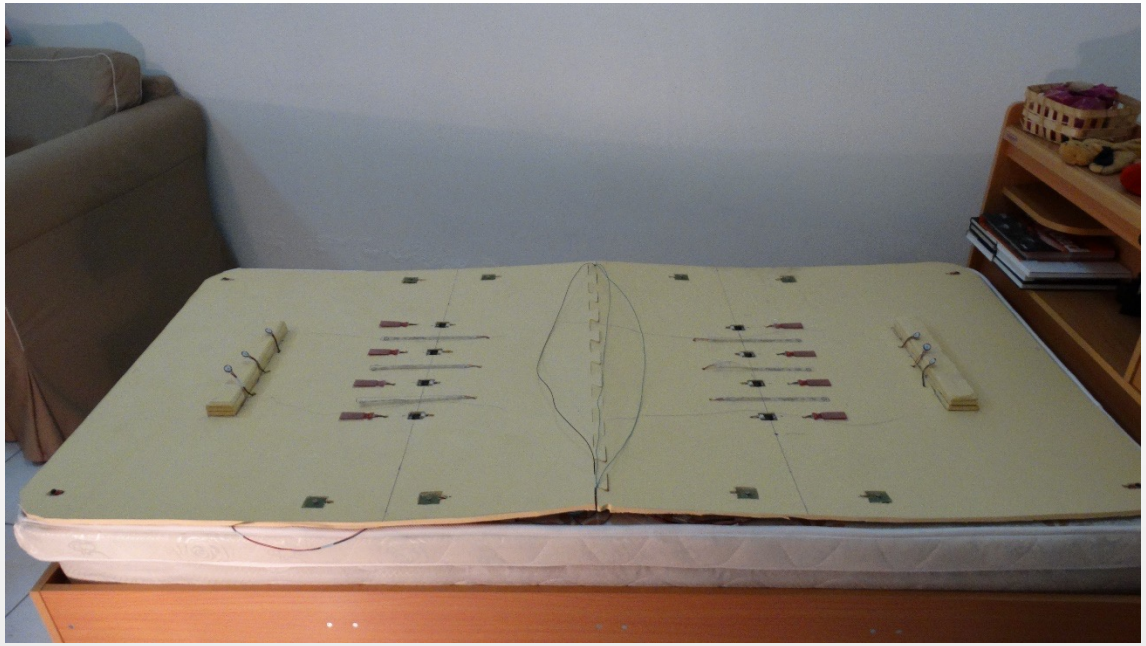
- User is alive
- Environment is quiet
- User places their neck on a prop

Flow chart


Register/Log in
Take physiological measurements
Send data to the server
Free of Noise?
True
False
Clean the data from noise
Run an evaluation algorithm
Detect pulse "spikes"
Detect cessation of lung movements
Detect hypopnea or snoring
Perform dignosis
Database of measurements
Store measurements and diagnosis
Send diagnosis to the website

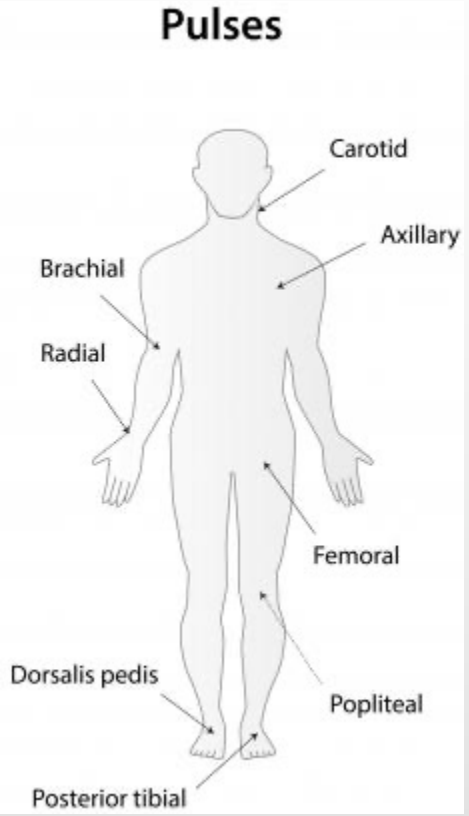
Mattress manufacturing

Mattress manufacturing



Testing

- Tests were performed to determine perfect positions for sensors' placement positions
- Software "stress" testing
- Testing of algorithms



Cost estimation

- Research & Development cost is $840.41
- Cost of a device for consumer-use is TBD

Impact of the project

- Decreased medical expenses
- Population’s health improvement
- Medical sphere can focus on other issues.

Thank You!

An Intelligent Bed for Diagnosis of Sleep Apnea (Extras)

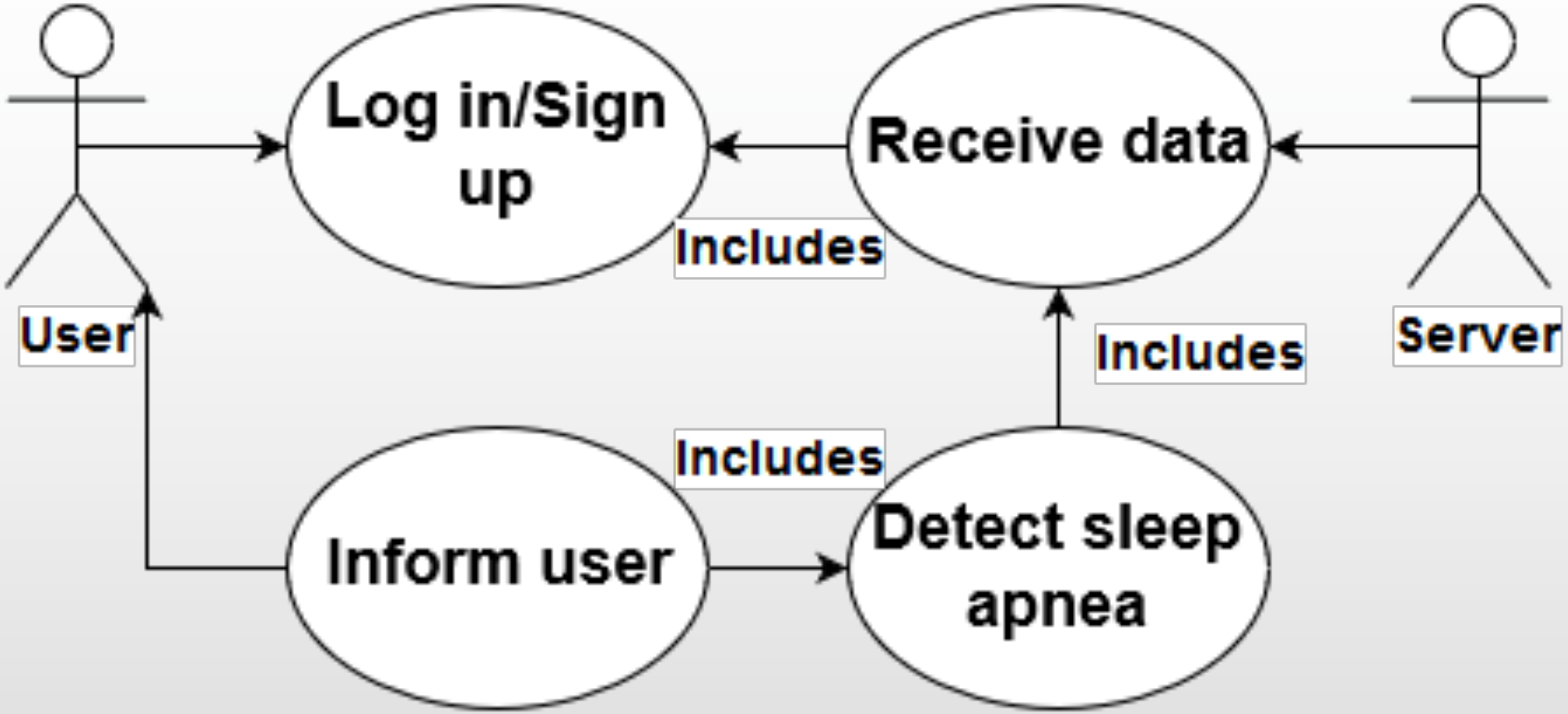
BY:

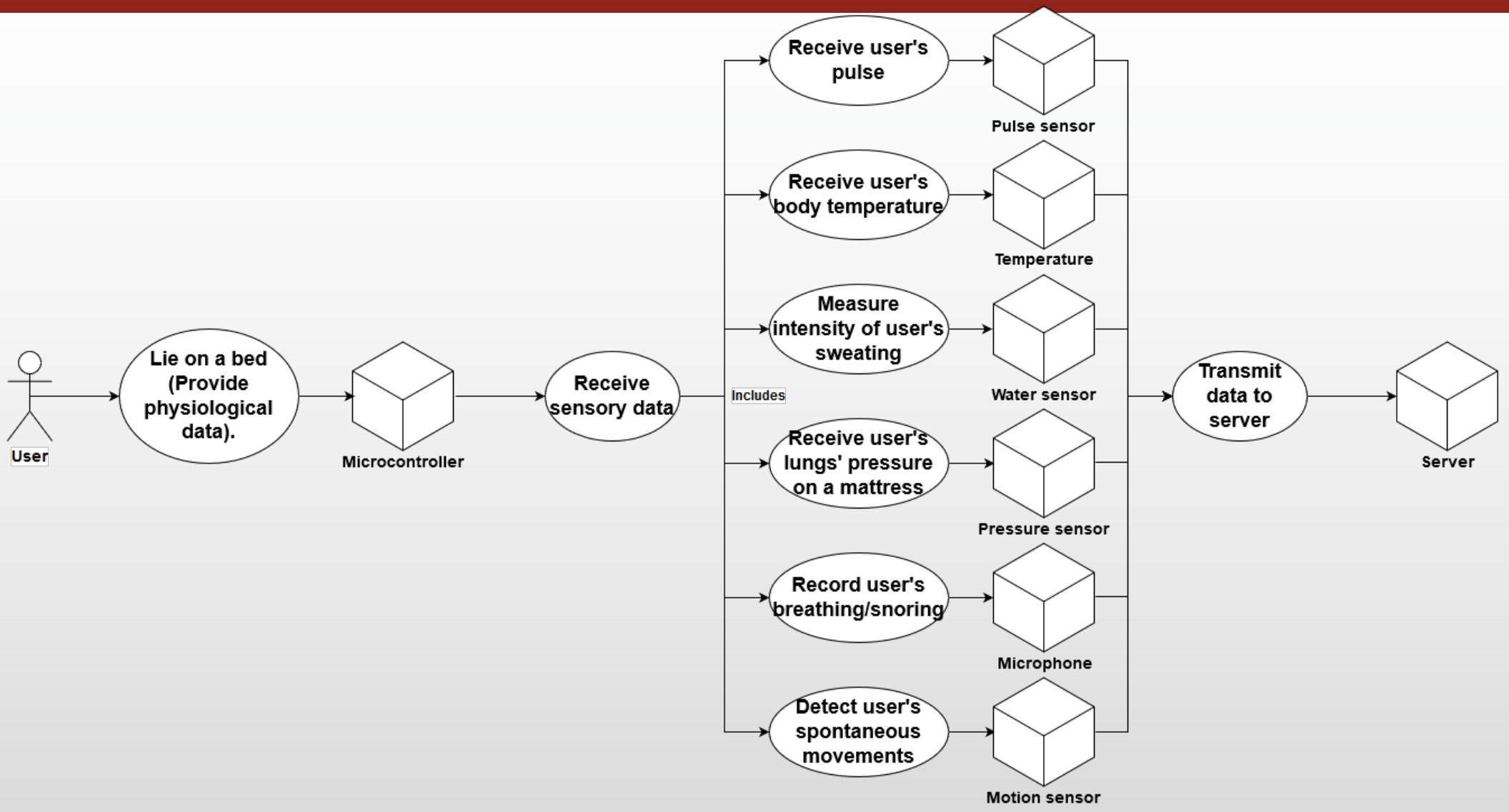
GERMAN SHEIN (48610)

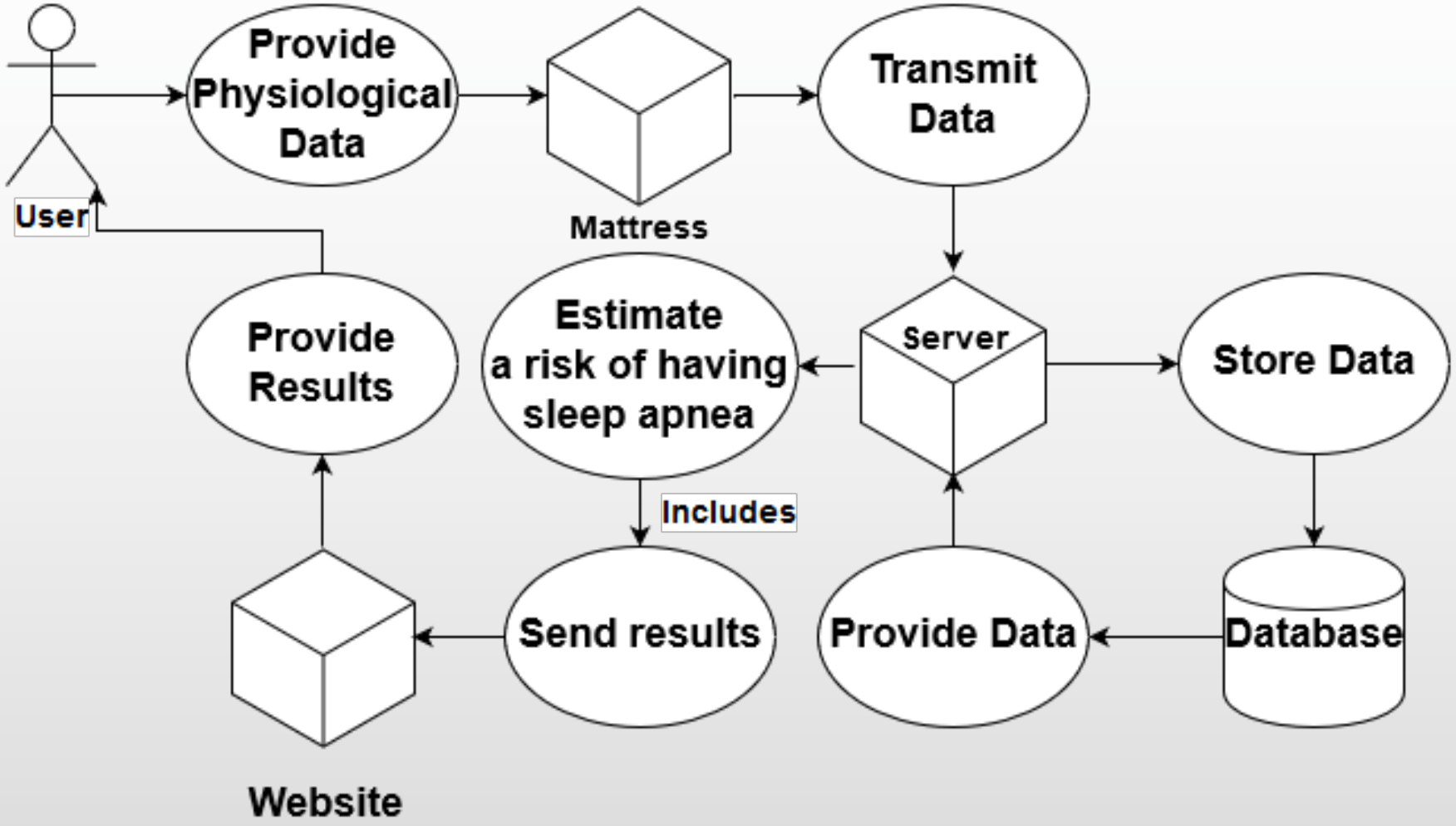
SANKAR SATHYANARAYANAN (48966)

ADVISORS: DR. MICHEL BERNARD PASQUIER AND DR. ASSIM SAGAHYROON

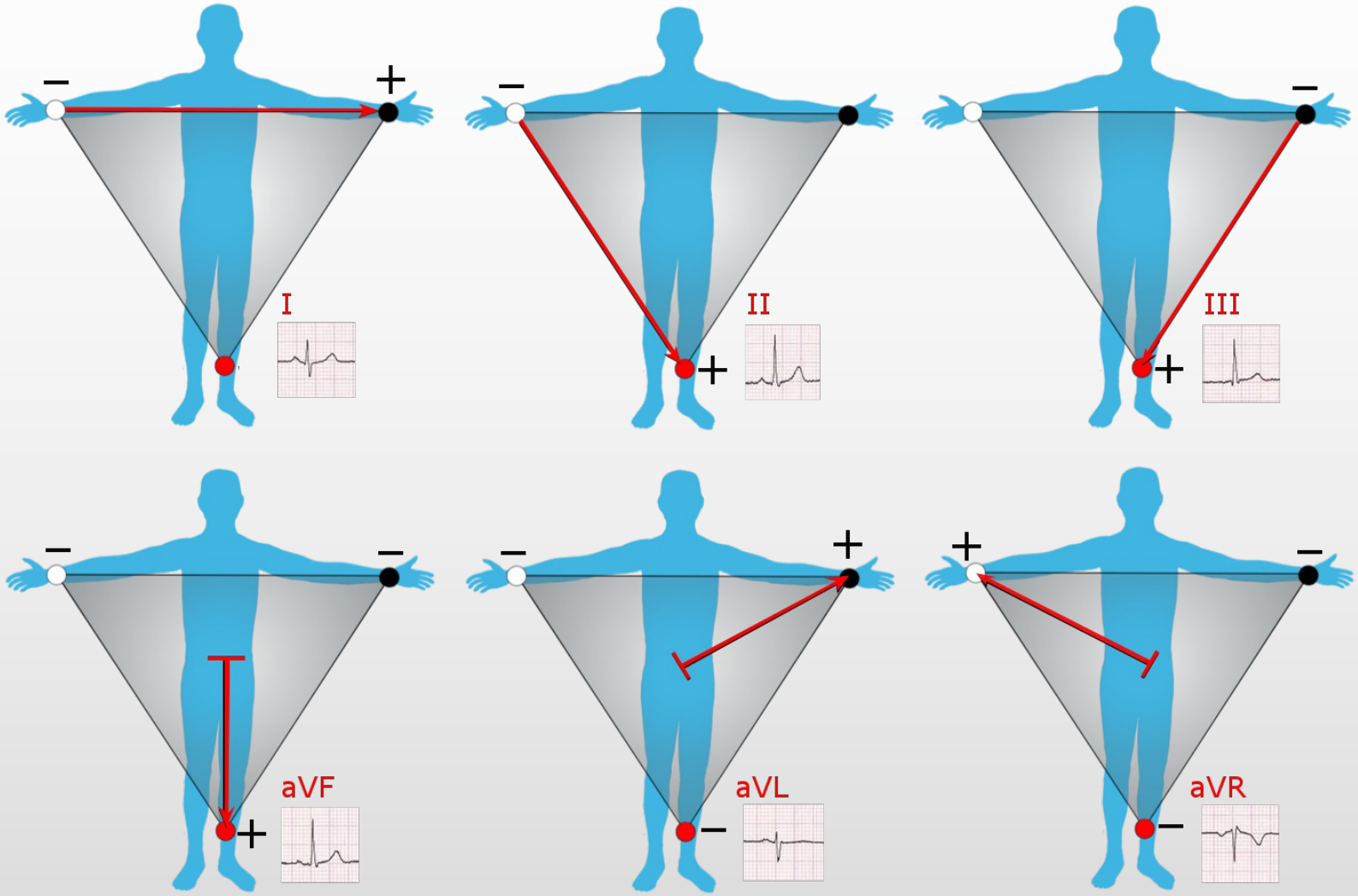
Use-case Diagrams

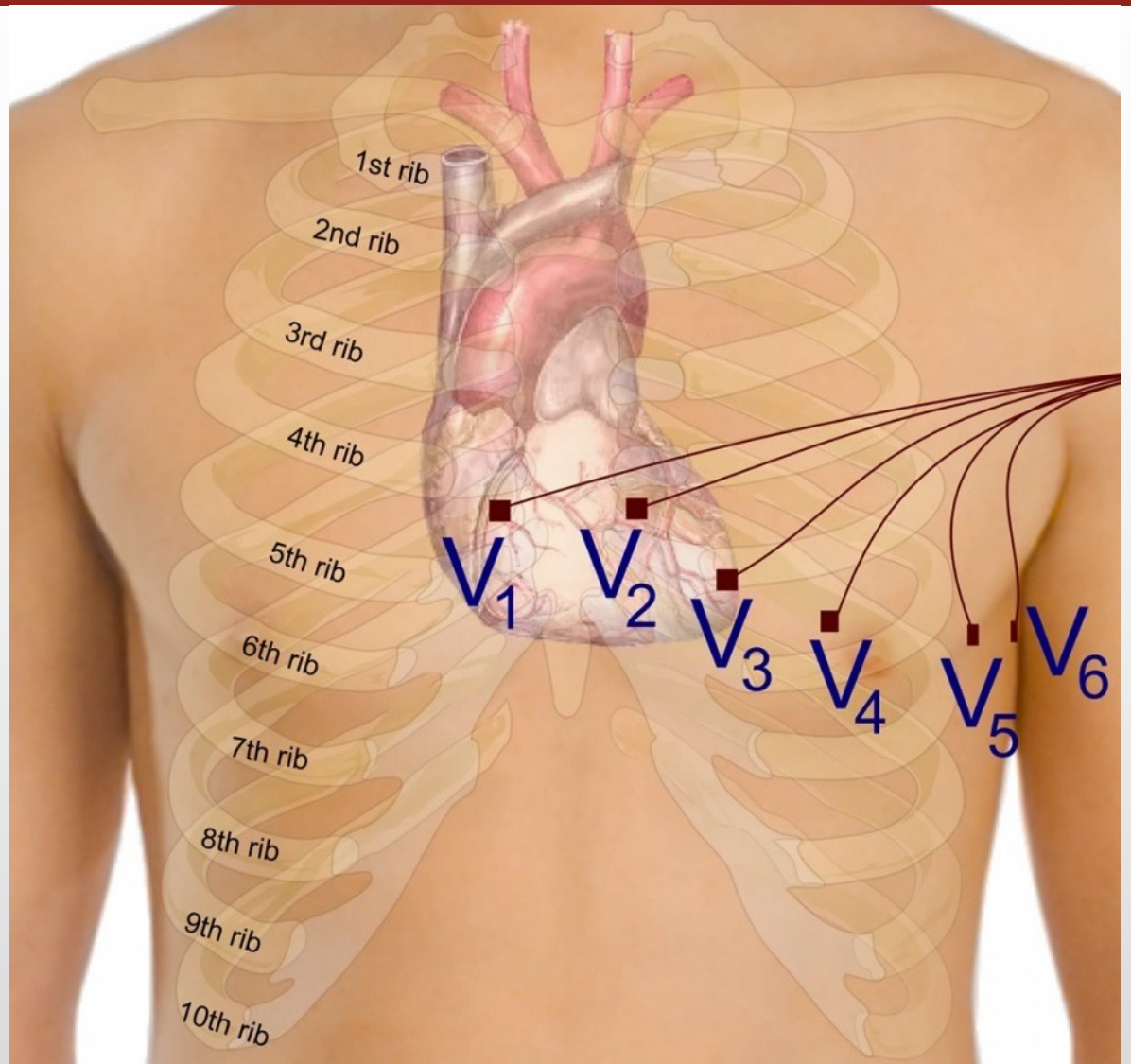



User
Lie on a bed (Provide physiological data).
Microcontroller
Receive sensory data
Includes
Receive user's pulse
Pulse sensor
Receive user's body temperature
Temperature
Measure intensity of user's sweating
Water sensor
Receive user's lungs' pressure on a mattress
Pressure sensor
Record user's breathing/snoring
Microphone
Detect user's spontaneous movements
Motion sensor
Transmit data to server
Server

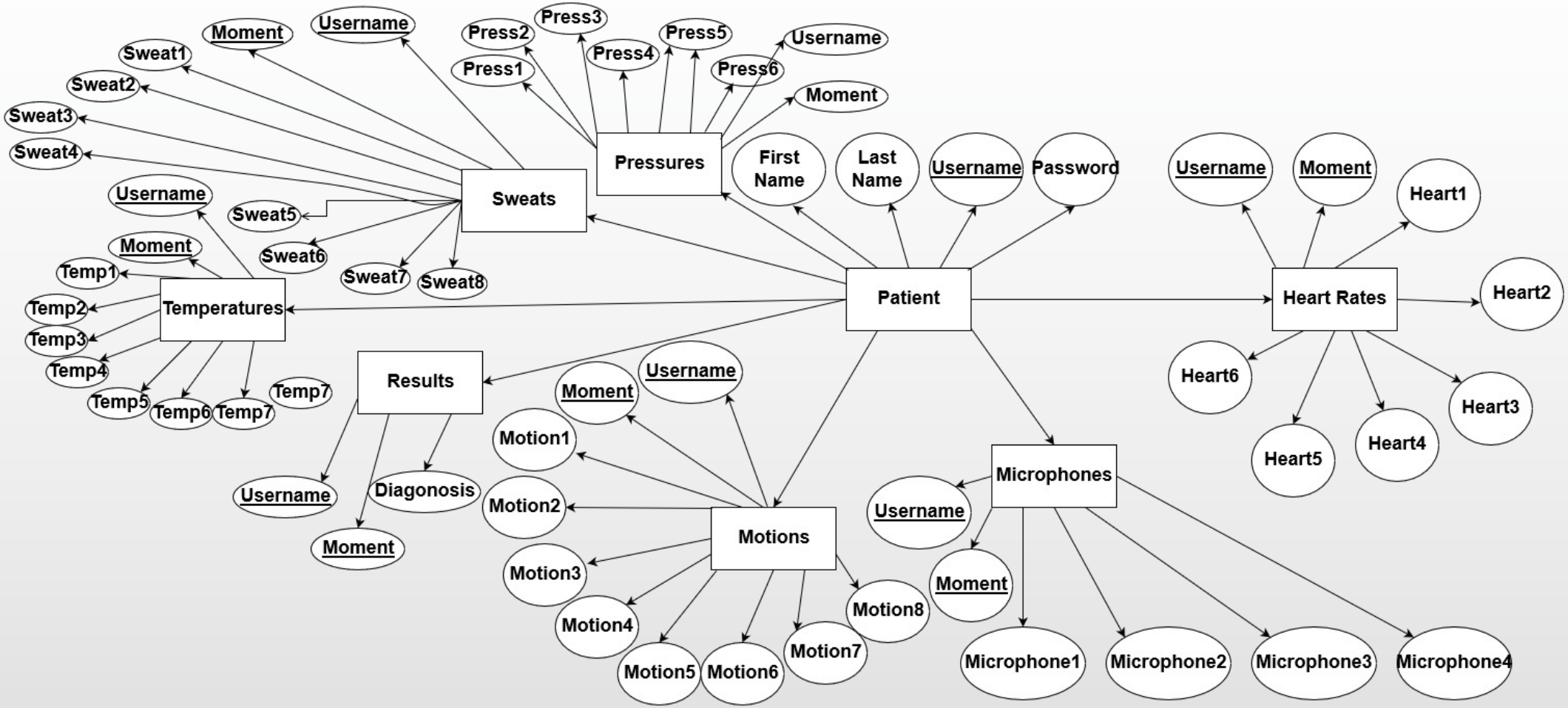

Provide Physiological Data
Transmit Data
User
Mattress
Provide Results
Estimate a risk of having sleep apnea
Server
Store Data
Includes
Send results
Provide Data
Database
Website

Electrocardiogram

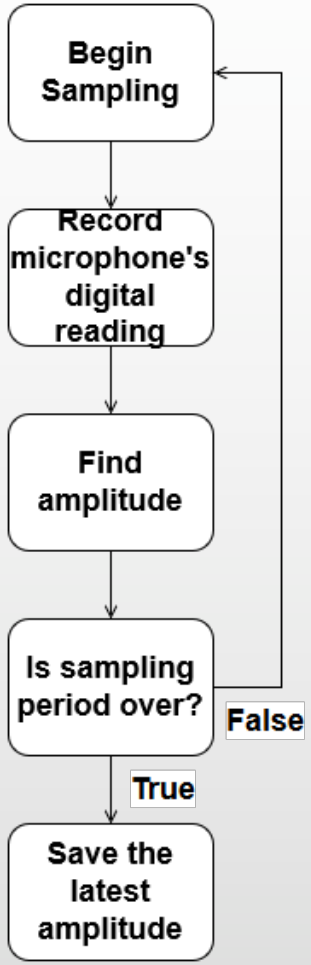


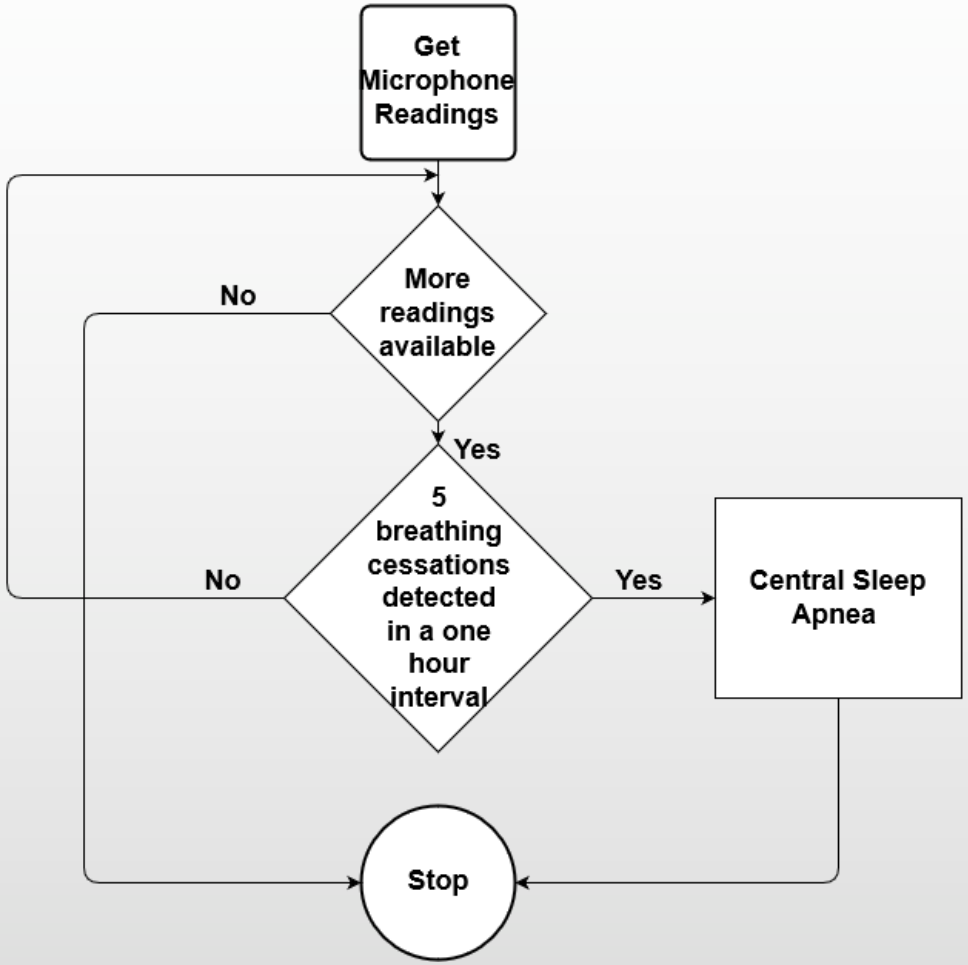

1st rib
2nd rib
3rd rib
4th rib
5th rib
6th rib
7th rib
8th rib
9th rib
10th rib
V1
V2
V3
V4
V5
V6

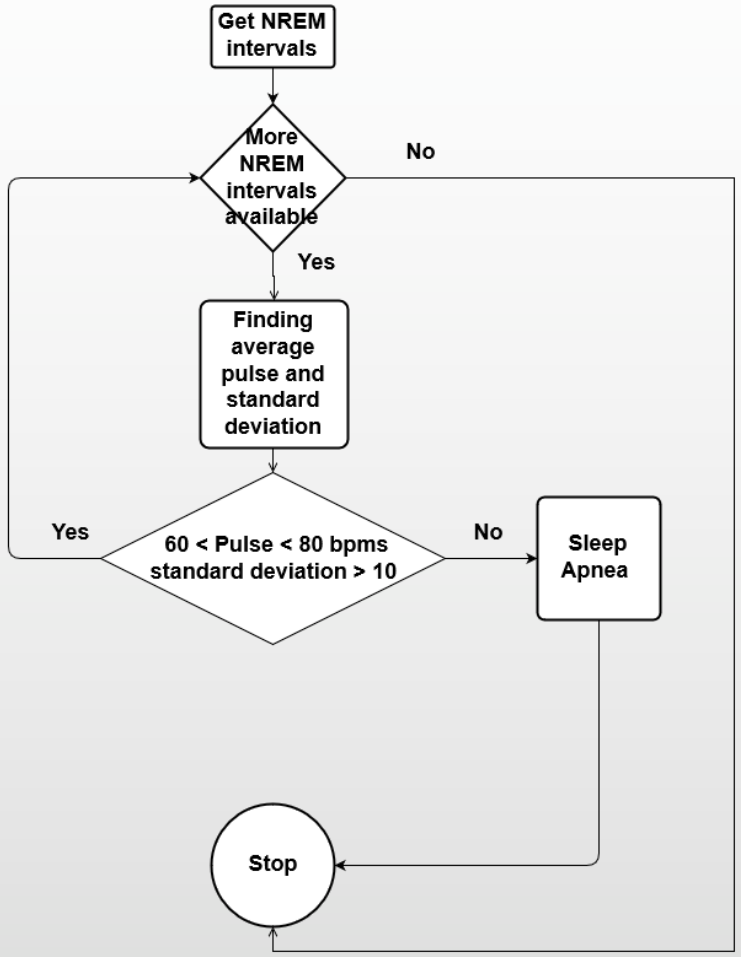
Database Schema

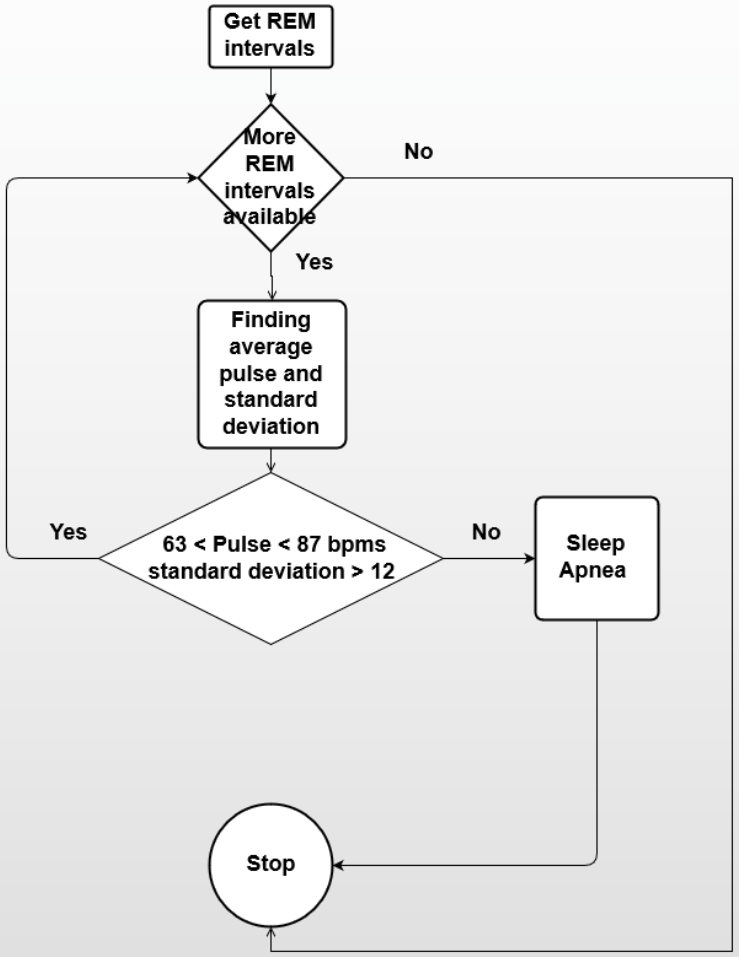


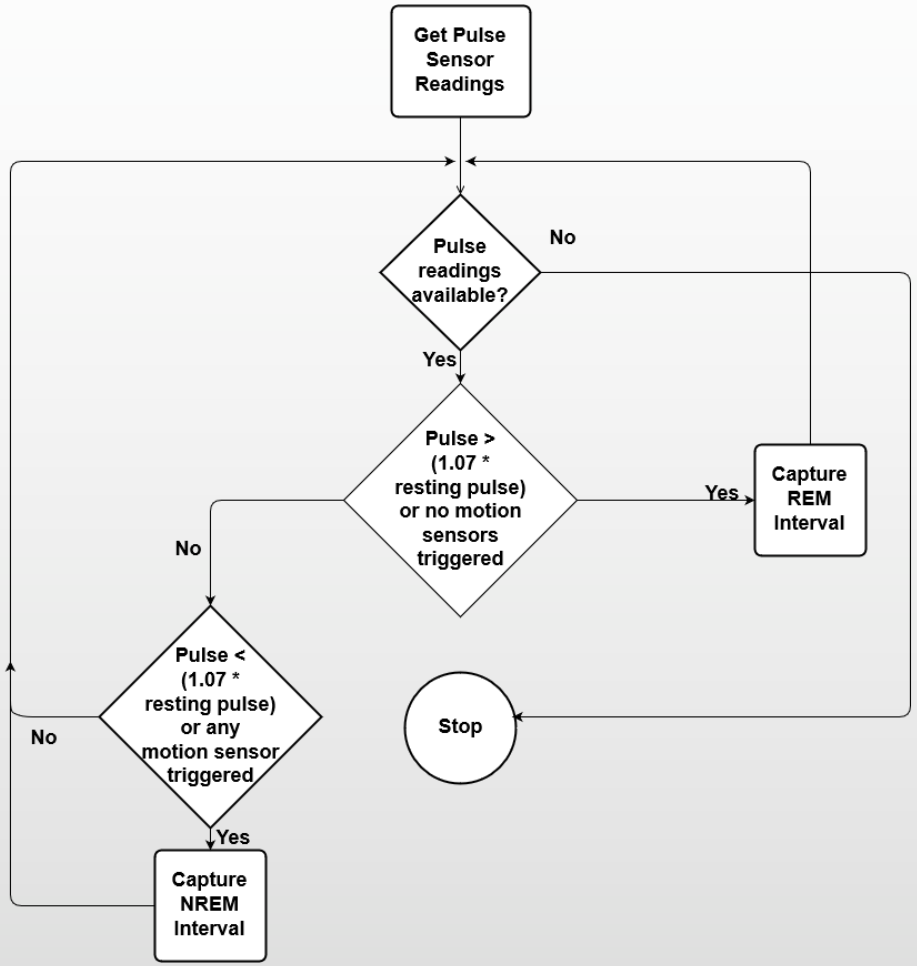
Flow charts

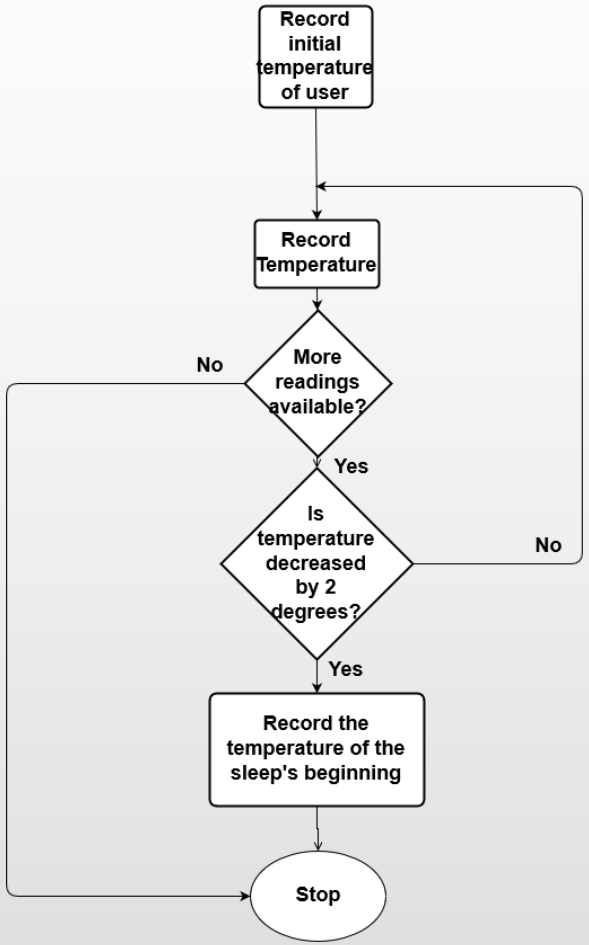

Begin Sampling
Record microphone's digital reading
Find amplitude
Is sampling period over?
False
True
Save the latest amplitude

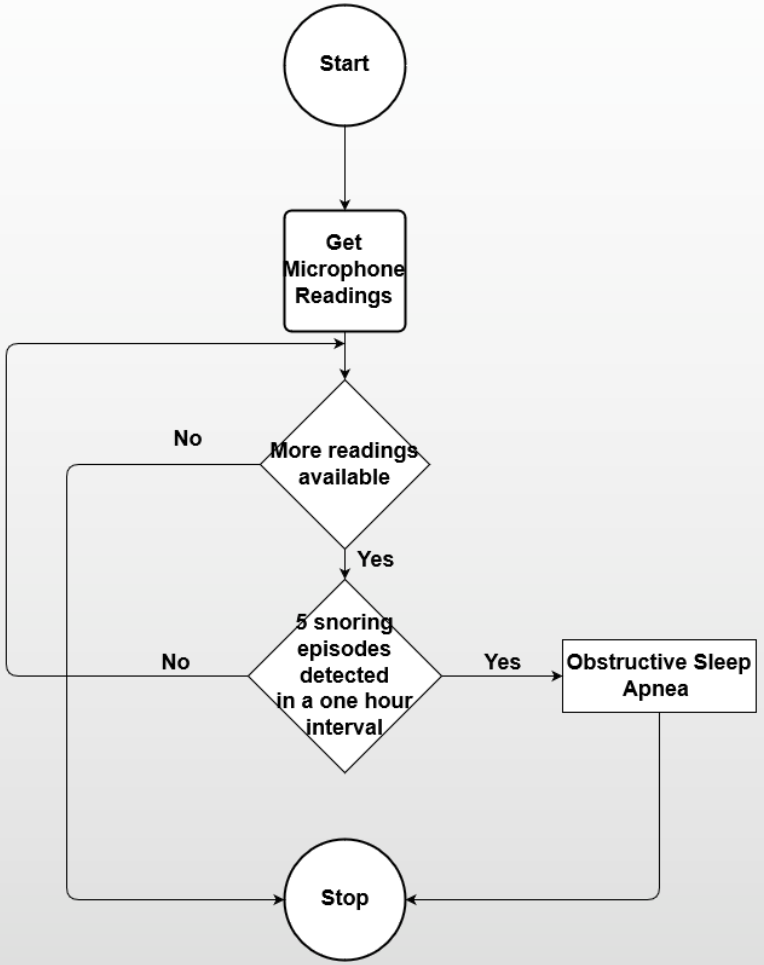

Get Microphone Readings
More readings available
No
Yes
5 breathing cessations detected in a one hour interval
No
Yes
Central Sleep Apnea
Stop

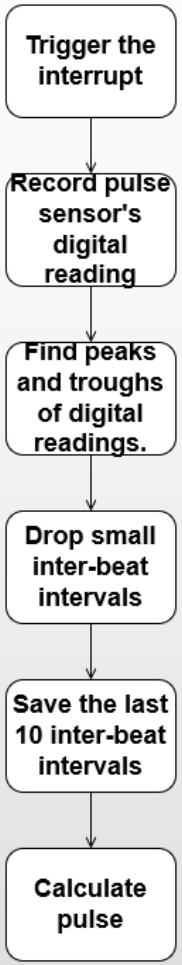

Get NREM intervals
More NREM intervals available
No
Yes
Finding average pulse and standard deviation
Yes
60 < Pulse < 80 bpms standard deviation > 10
No
Sleep Apnea
Stop


Get REM intervals
More REM intervals available
No
Yes
Finding average pulse and standard deviation
Yes
63 < Pulse < 87 bpms standard deviation > 12
No
Sleep Apnea
Stop

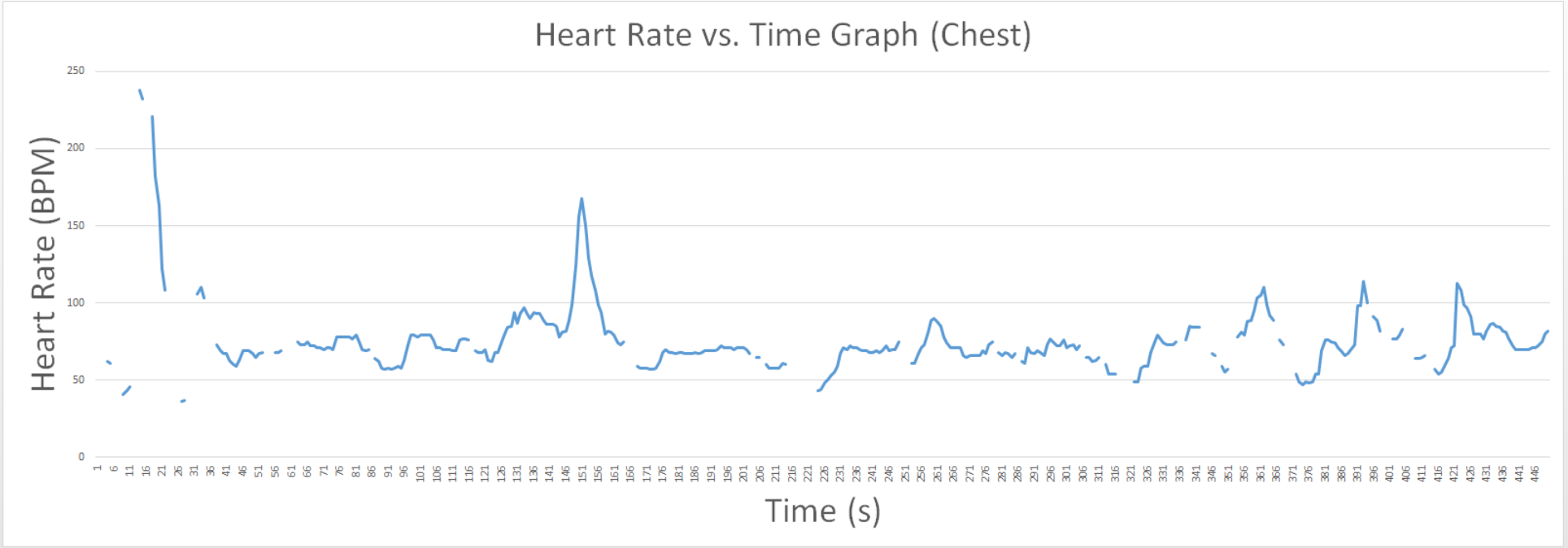

Get Pulse Sensor Readings
Pulse readings available?
No
Yes
Pulse > (1.07 * resting pulse) or no motion sensors triggered
Yes
Capture REM Interval
No
Pulse < (1.07 * resting pulse) or any motion sensor triggered
No
Stop
Yes
Capture NREM Interval

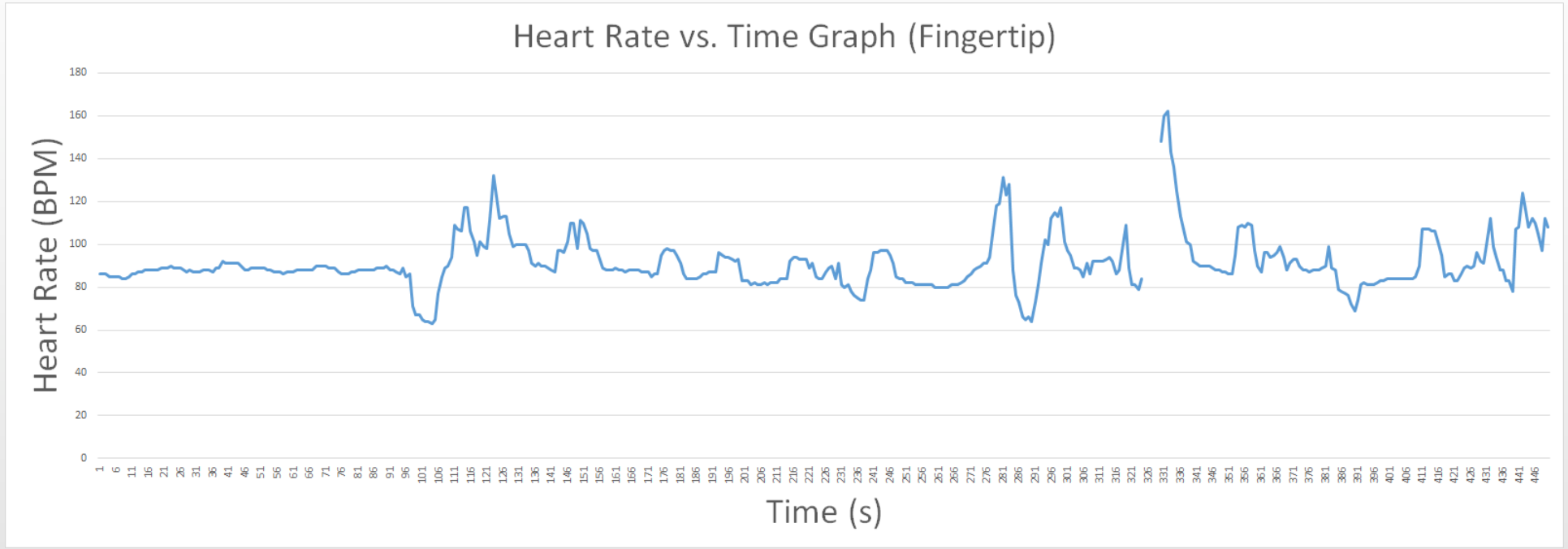

Record initial temperature of user
Record Temperature
More readings available?
No
Yes
Is temperature decreased by 2 degrees?
No
Yes
Record the temperature of the sleep's beginning
Stop

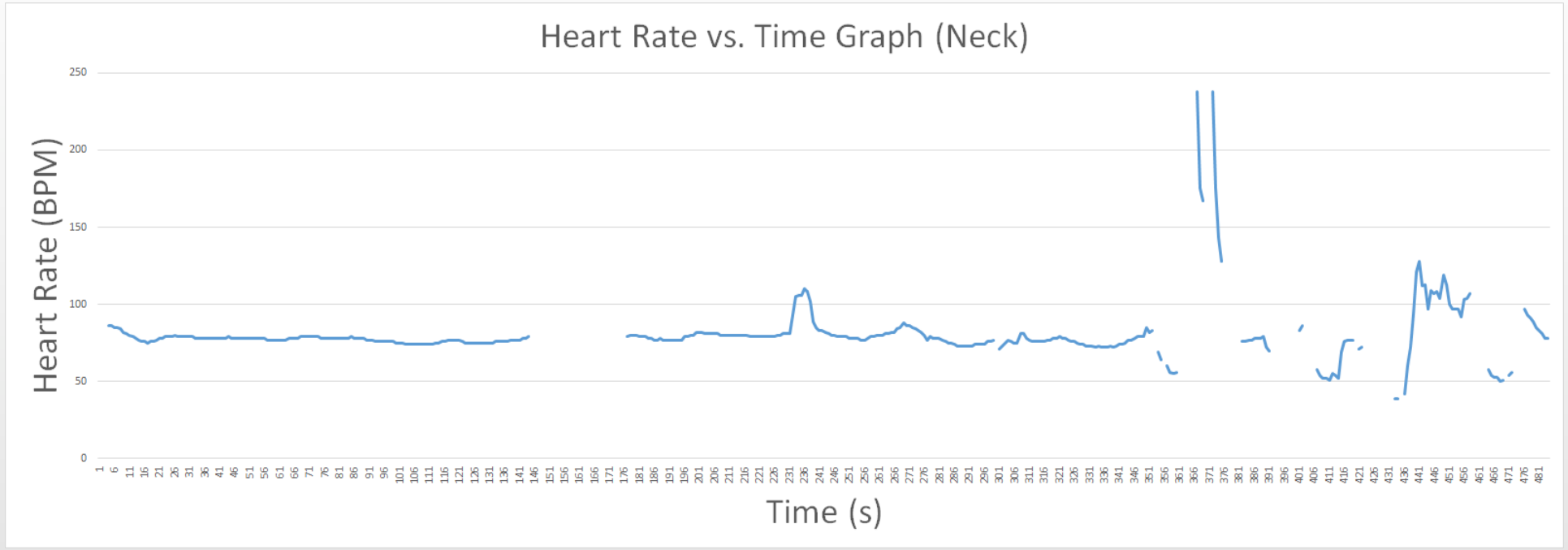

Start
Get Microphone Readings
More readings available
No
Yes
5 snoring episodes detected in a one hour interval
No
Yes
Obstructive Sleep Apnea
Stop

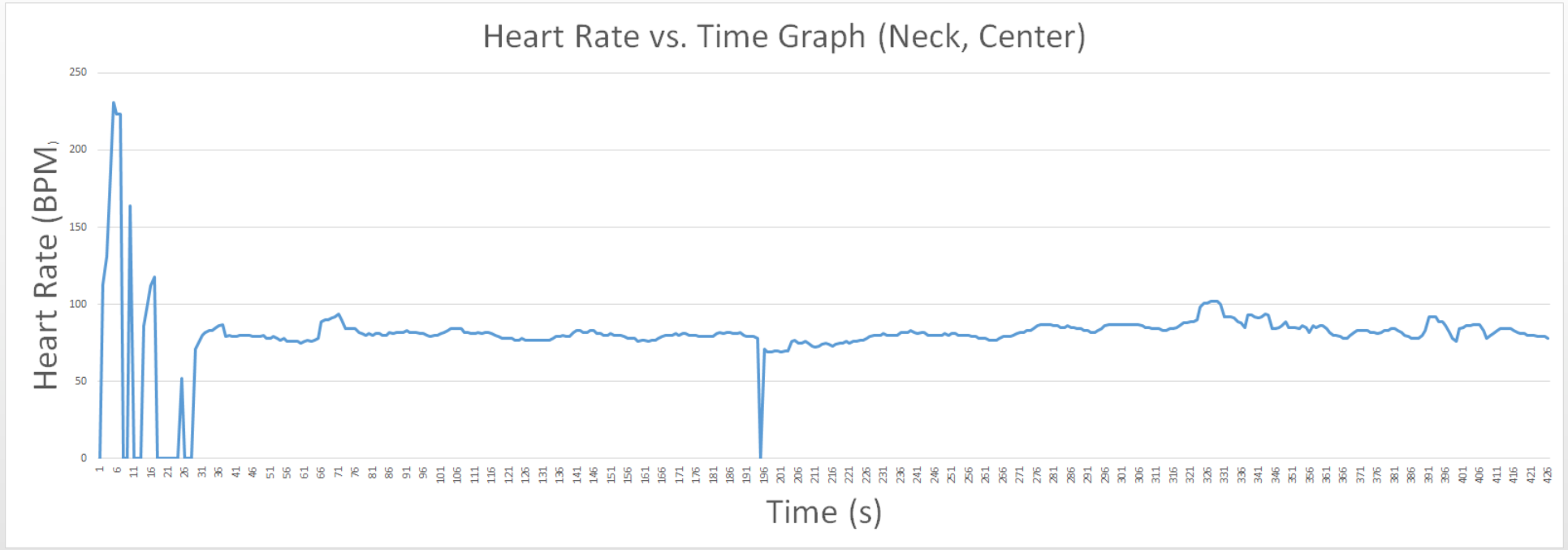

Trigger the interrupt
Record pulse sensor's digital reading
Find peaks and troughs of digital readings.
Drop small inter-beat intervals
Save the last 10 inter-beat intervals
Calculate pulse

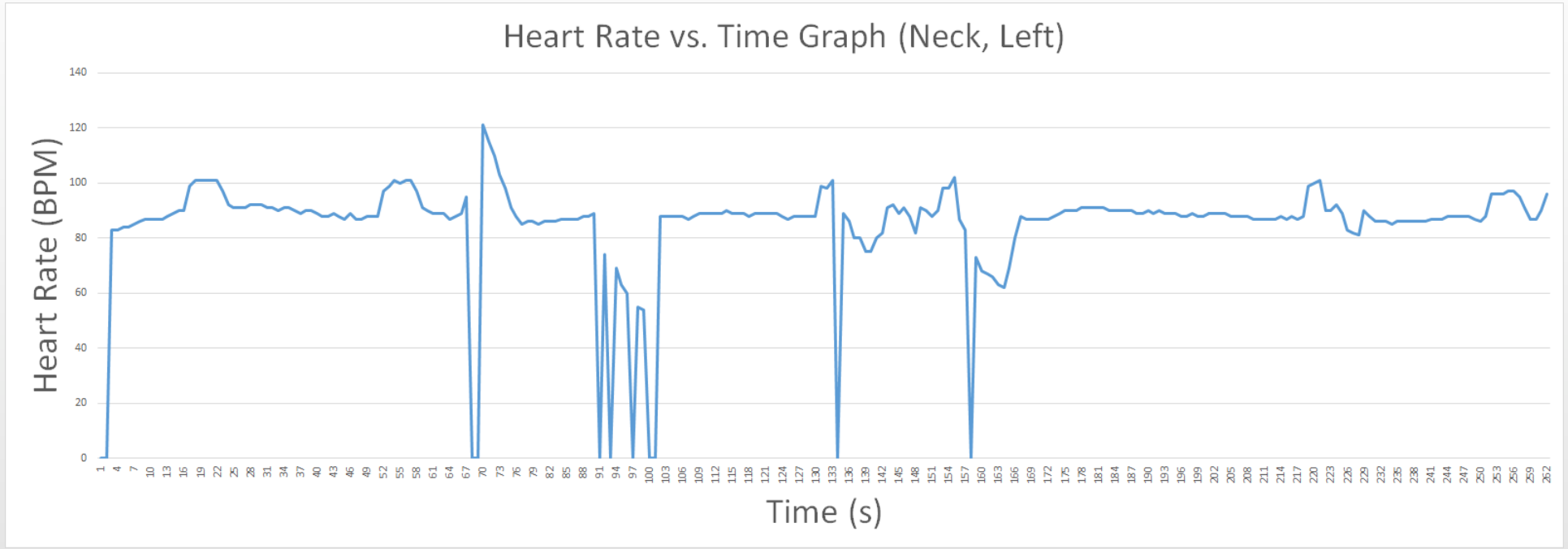
Hardware testing

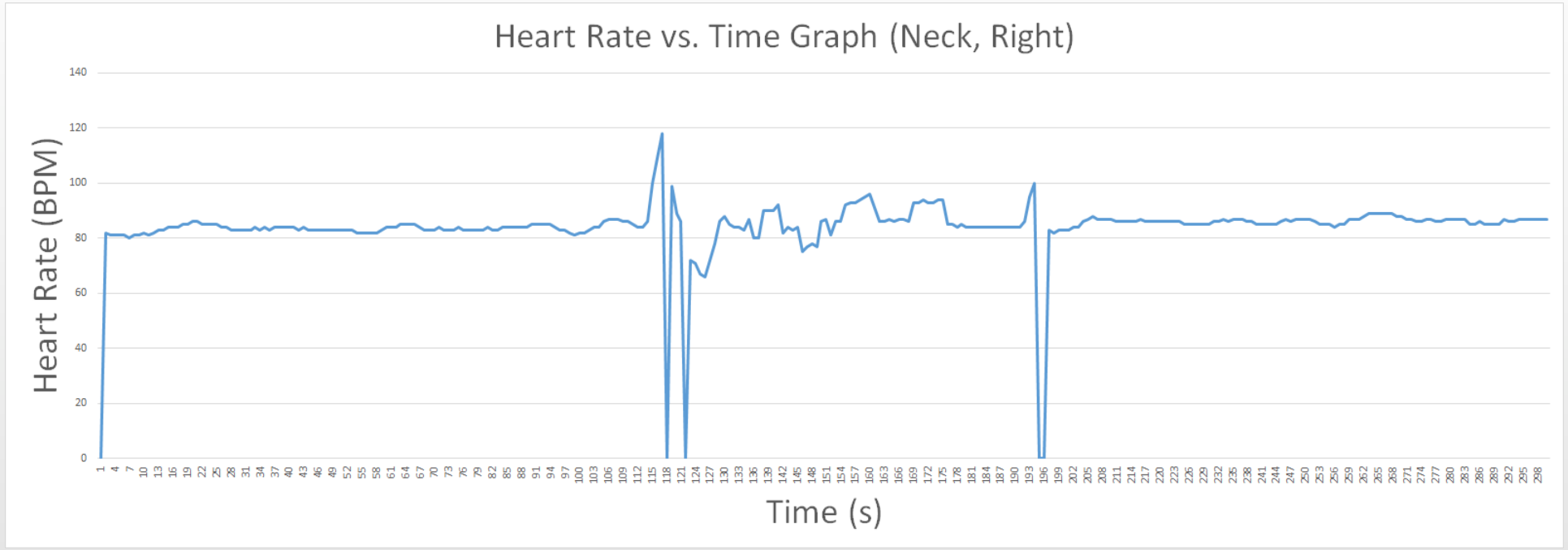


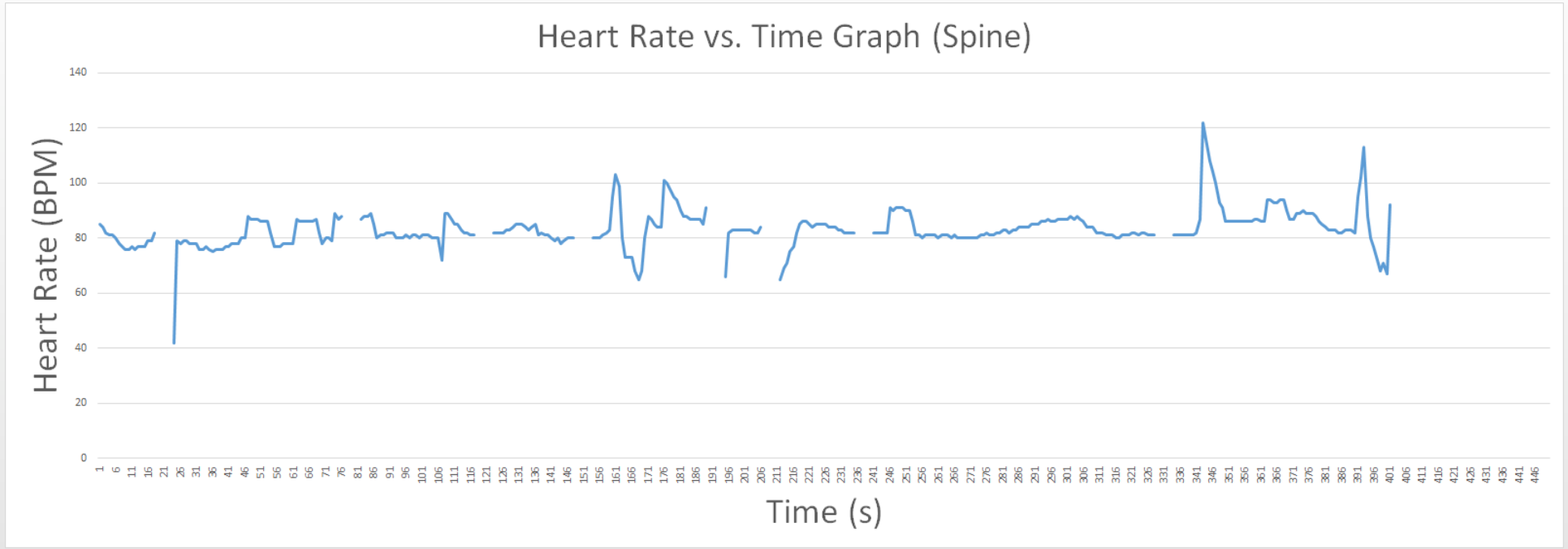

Heart Rate vs. Time Graph (Fingertip)
Heart Rate (BPM)
180
160
140
120
100
80
60
40
20
0
Time (s)

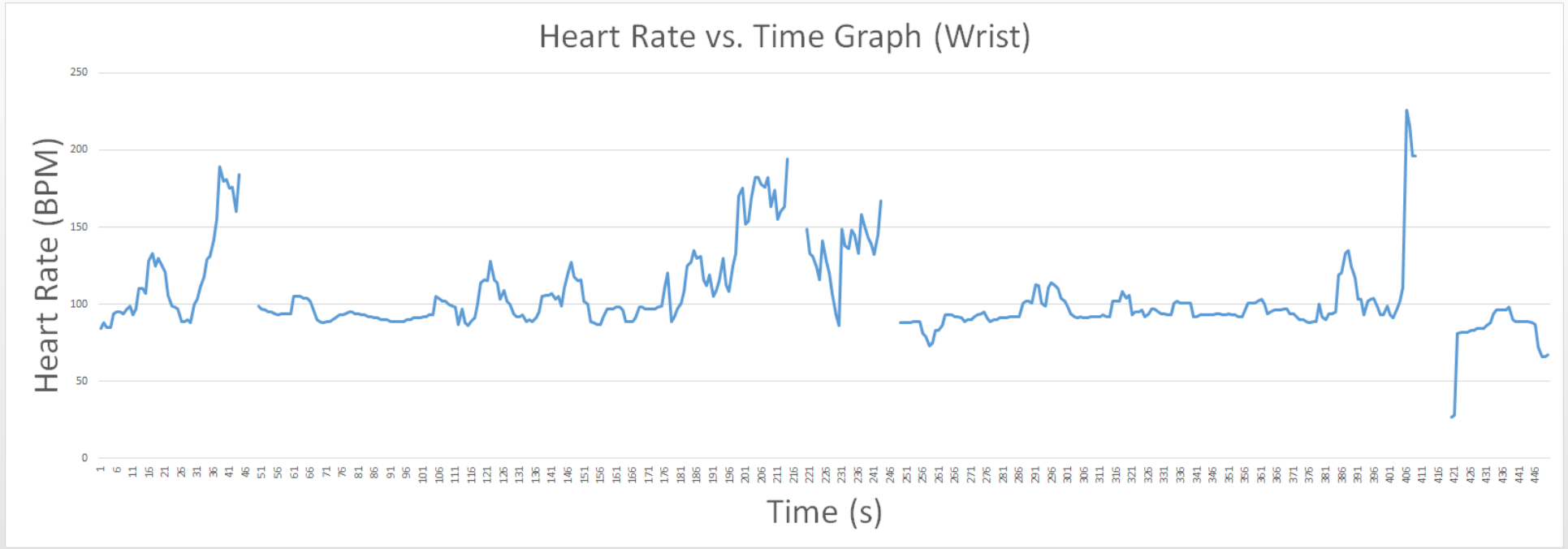

Heart Rate vs. Time Graph (Neck)
Heart Rate (BPM)
250
200
150
100
50
0
Time (s)

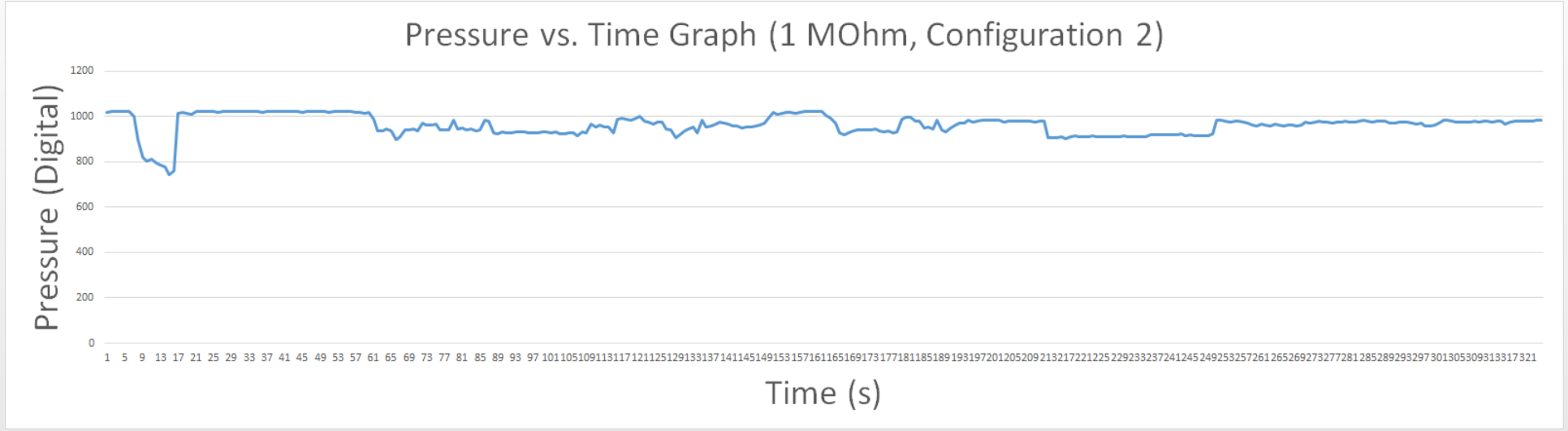

Heart Rate vs. Time Graph (Neck, Center)
Heart Rate (BPM)
Time (s)
250
200
150
100
50
0

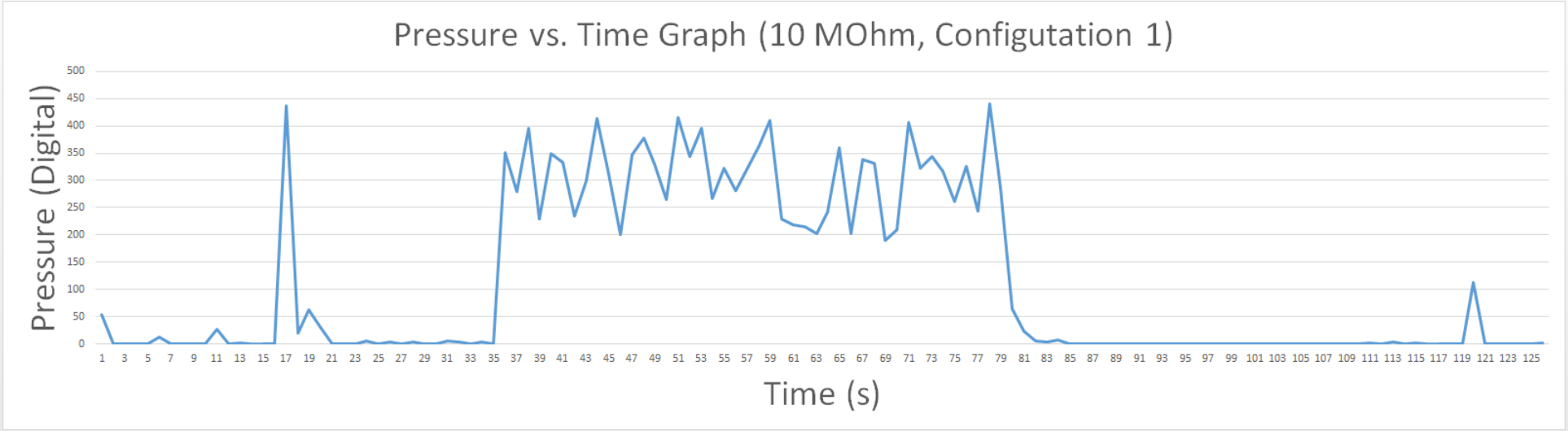

Heart Rate vs. Time Graph (Neck, Left)
Heart Rate (BPM)
Time (s)
0
20
40
60
80
100
120
140

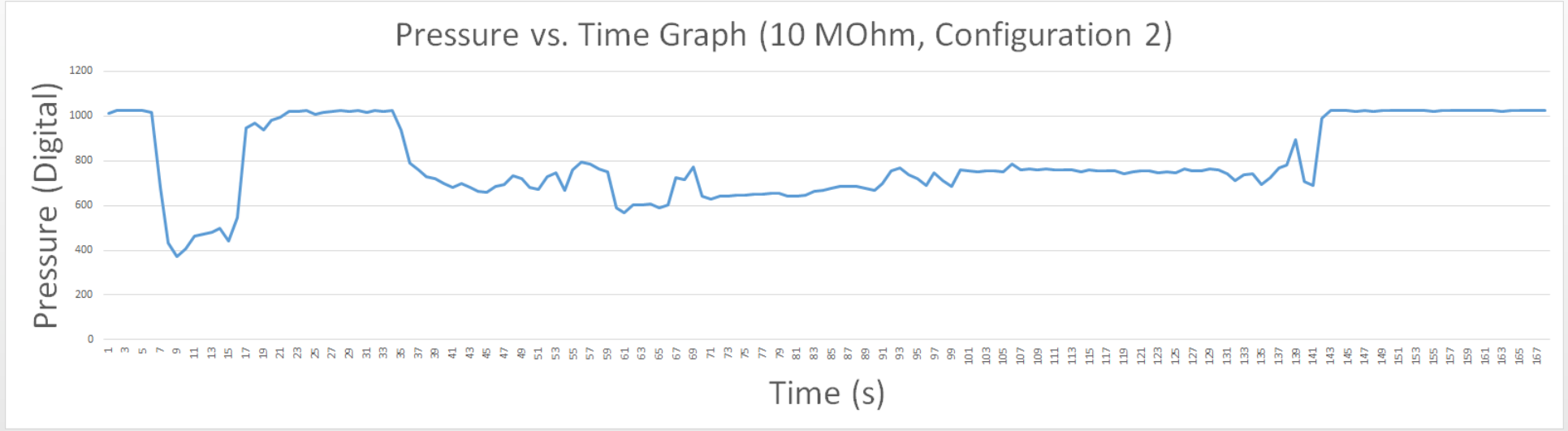

Heart Rate vs. Time Graph (Neck, Right)
Heart Rate (BPM)
140
120
100
80
60
40
20
0
Time (s)

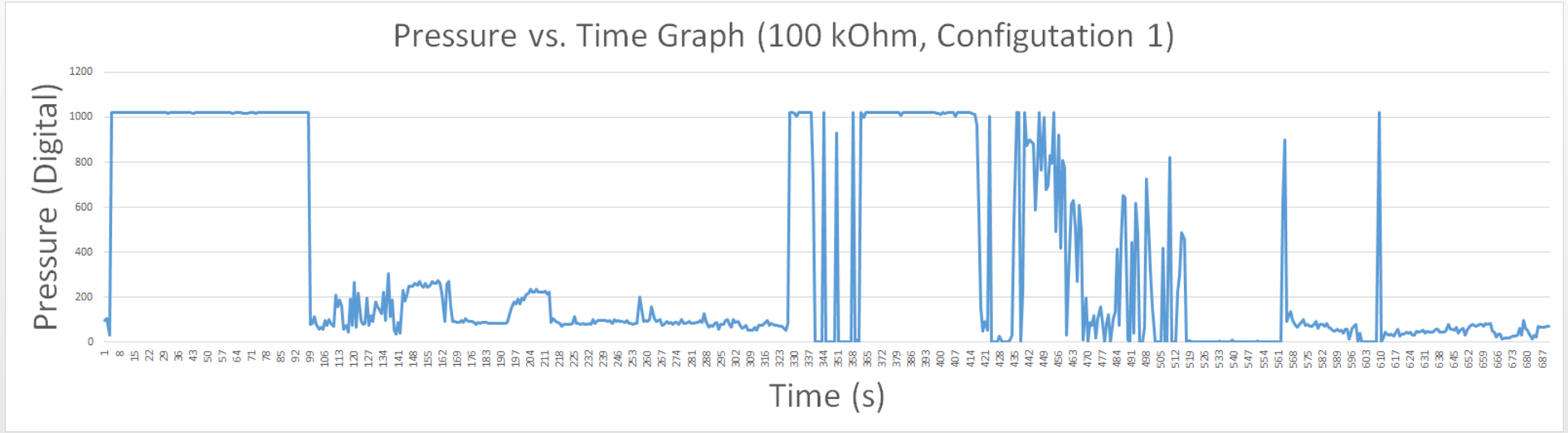

Heart Rate vs. Time Graph (Spine)
Heart Rate (BPM)
140
120
100
80
60
40
20
0
Time (s)

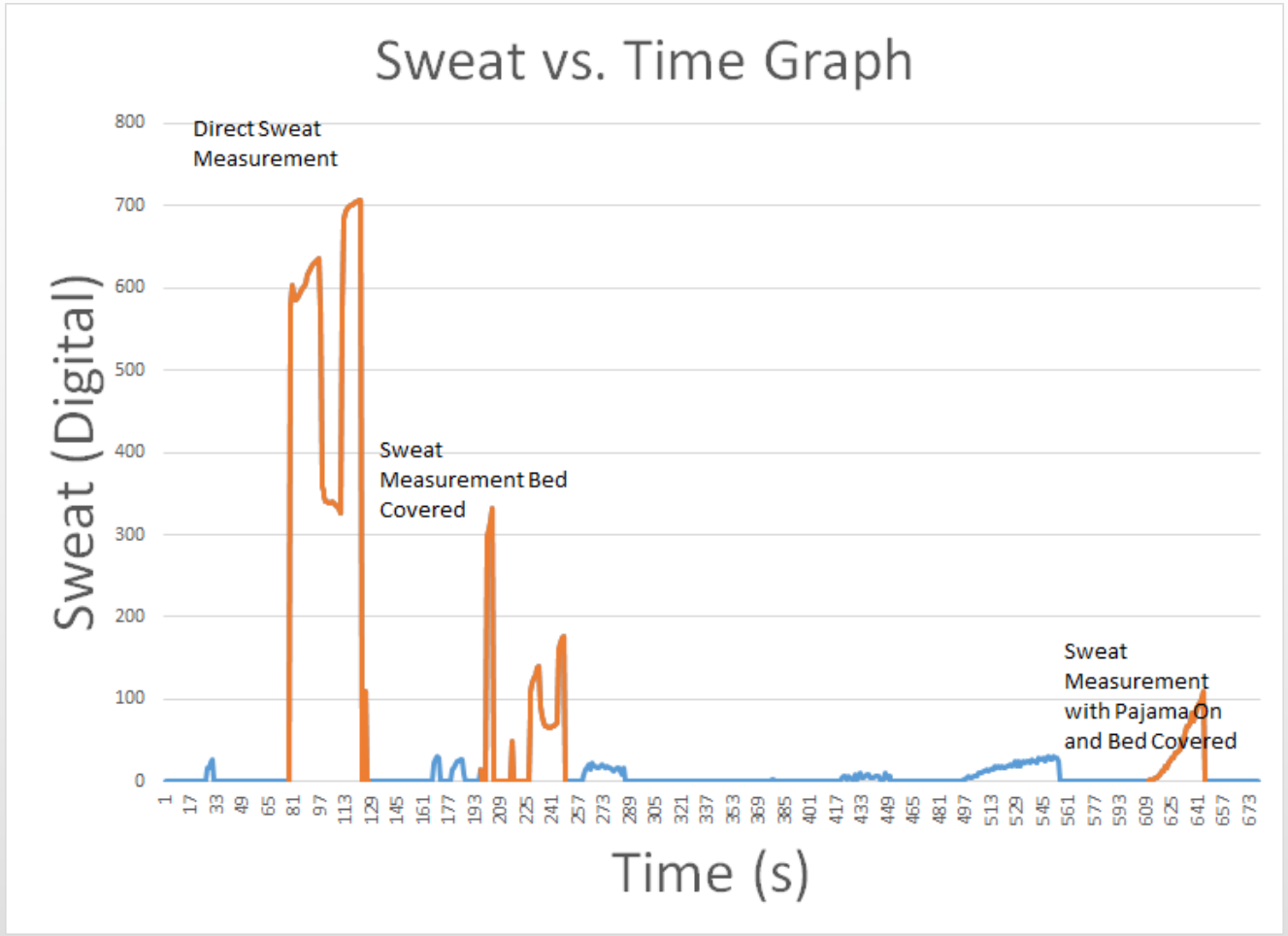

Heart Rate vs. Time Graph (Wrist)
Heart Rate (BPM)
250
200
150
100
50
0
Time (s)

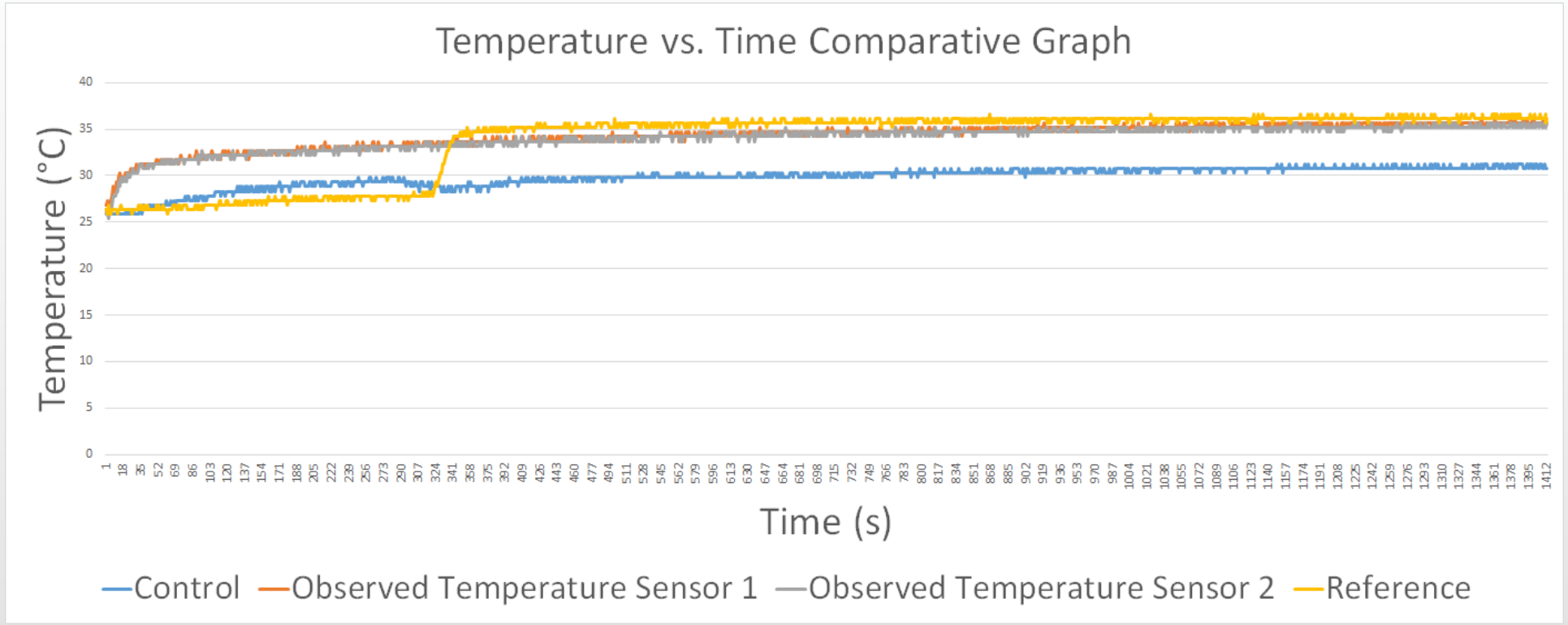

Pressure vs. Time Graph (1 MOhm, Configuration 2)
Pressure (Digital)
1200
1000
800
600
400
200
0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113 117 121 125 129 133 137 141 145 149 153 157 161 165 169 173 177 181 185 189 193 197 201 205 209 213 217 221 225 229 233 237 241 245 249 253 257 261 265 269 273 277 281 285 289 293 297 301 305 309 313 317 321
Time (s)

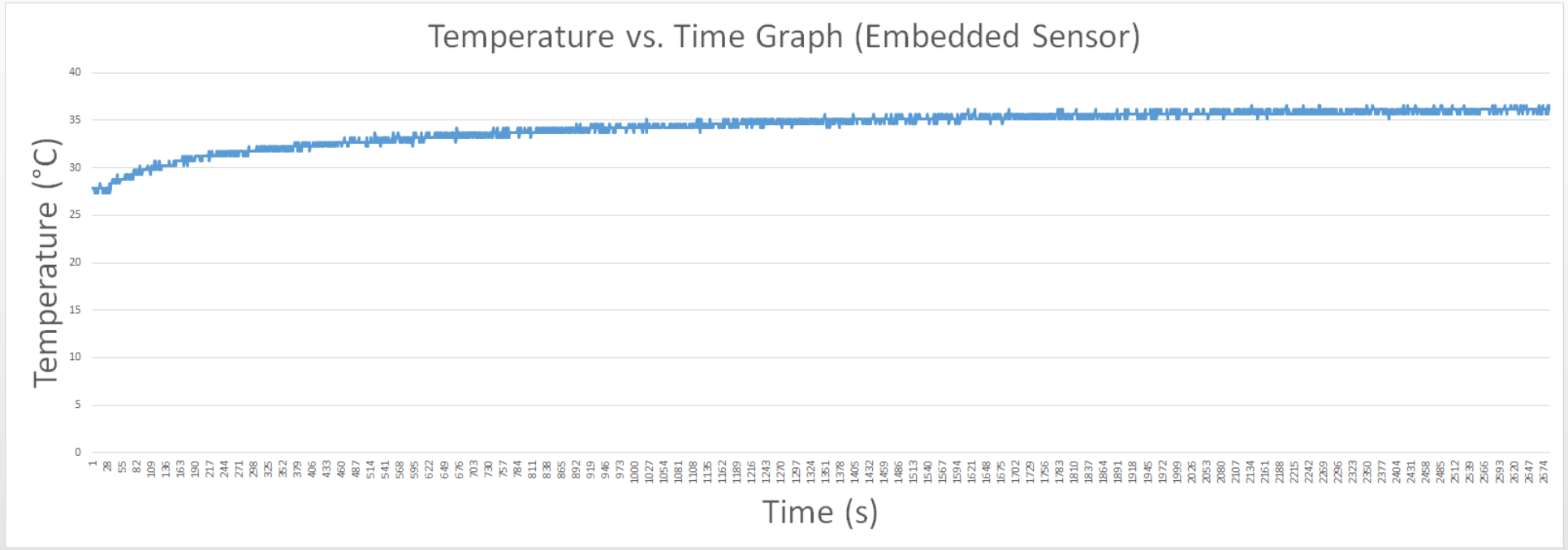

Pressure vs. Time Graph (10 MOhm, Configutation 1)
Pressure (Digital)
500
450
400
350
300
250
200
150
100
50
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95 97 99 101 103 105 107 109 111 113 115 117 119 121 123 125
Time (s)

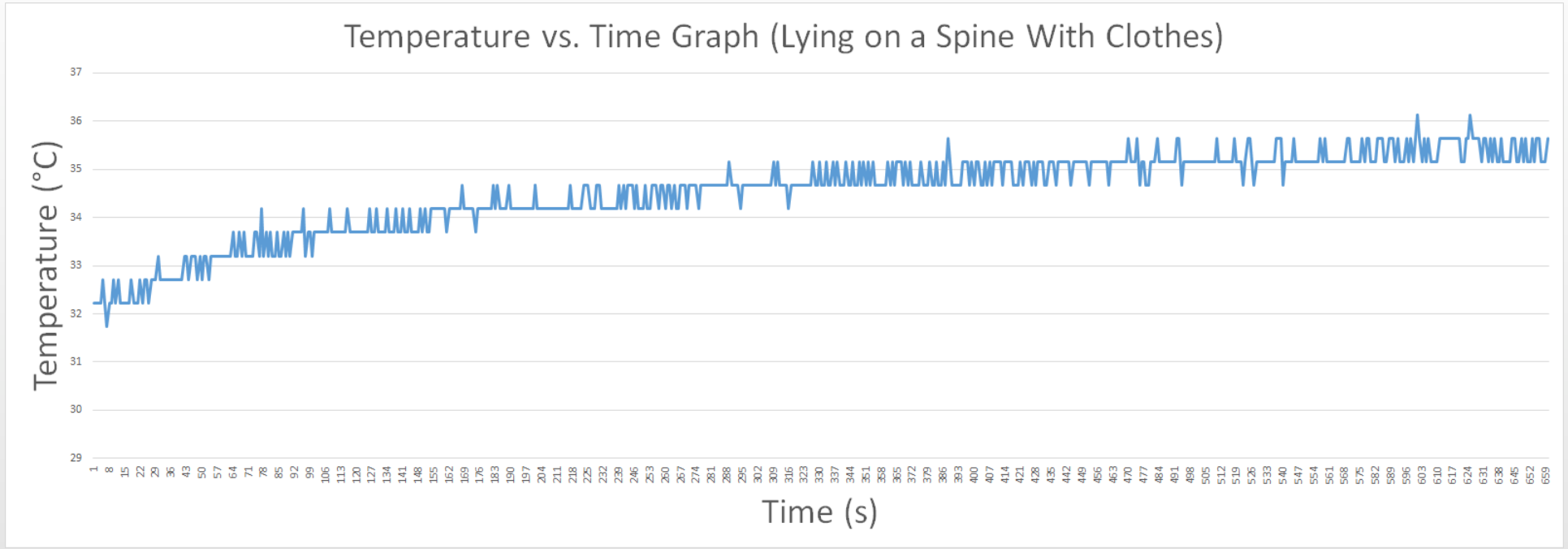

Pressure vs. Time Graph (10 MOhm, Configuration 2)
Pressure (Digital)
1200
1000
800
600
400
200
0
Time (s)

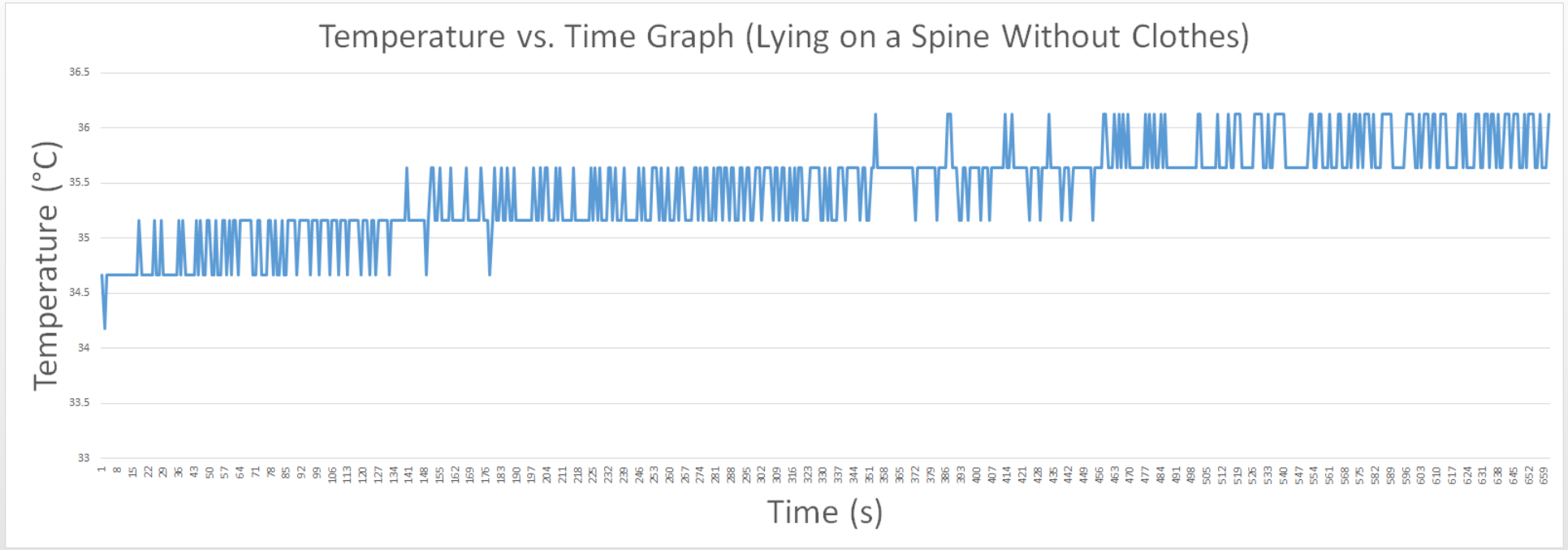

Pressure vs. Time Graph (100 kOhm, Configutation 1)
Pressure (Digital)
1200
1000
800
600
400
200
0
Time (s)

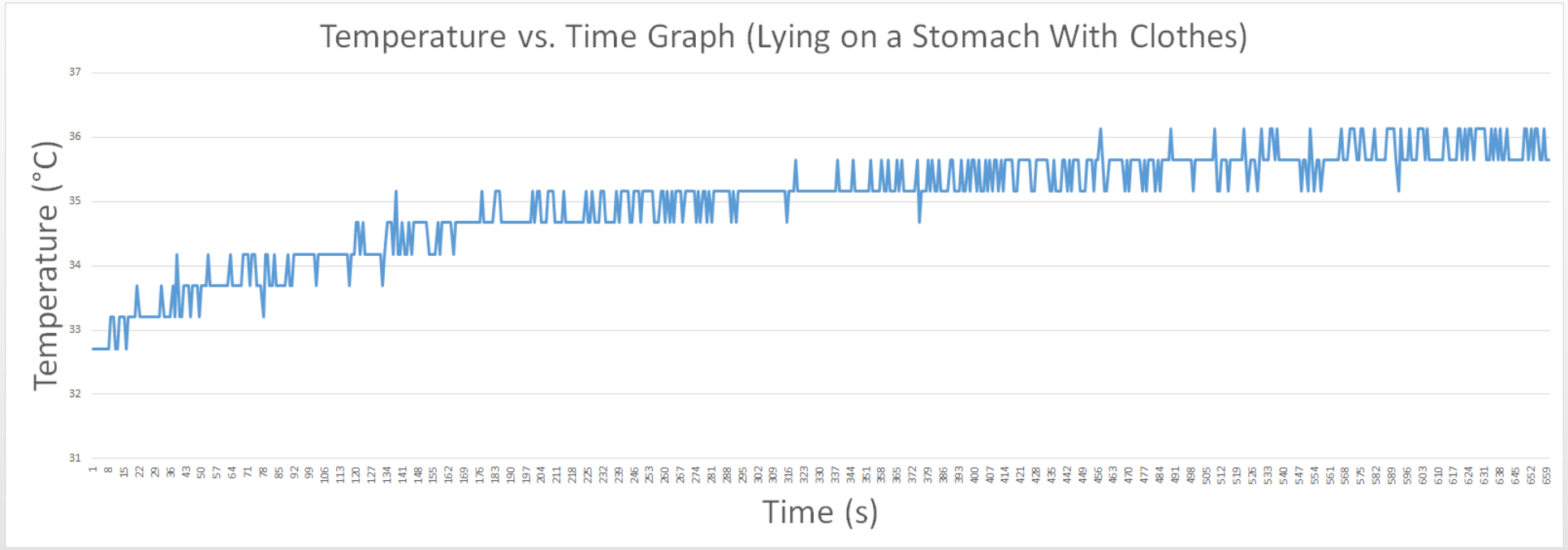

Sweat vs. Time Graph
Sweat (Digital)
Time (s)
Direct Sweat Measurement
Sweat Measurement Bed Covered
Sweat Measurement with Pajama On and Bed Covered
800
700
600
500
400
300
200
100
0
1
17
33
49
65
81
97
113
129
145
161
177
193
209
225
241
257
273
289
305
321
337
353
369
385
401
417
433
449
465
481
497
513
529
545
561
577
593
609
625
641
657
673

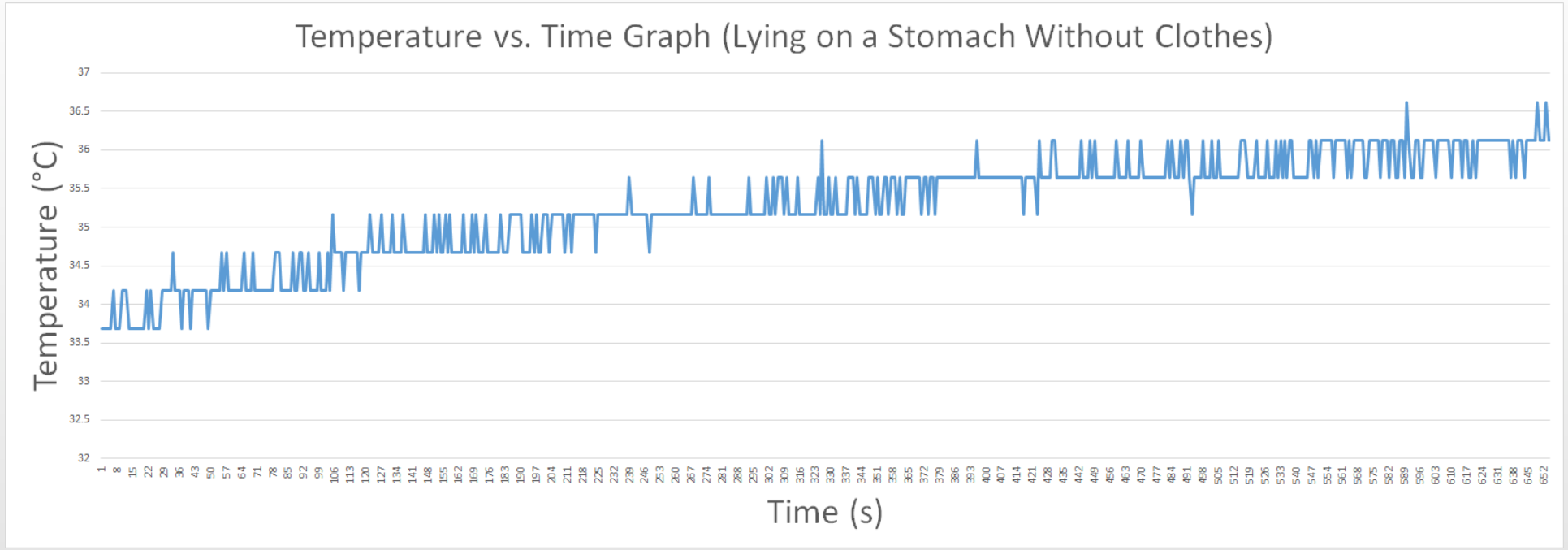

Temperature vs. Time Comparative Graph
Temperature (°C)
0
5
10
15
20
25
30
35
40
1
18
35
52
69
86
103
120
137
154
171
188
205
222
239
256
273
290
307
324
341
358
375
392
409
426
443
460
477
494
511
528
545
562
579
596
613
630
647
664
681
698
715
732
749
766
783
800
817
834
851
868
885
902
919
936
953
970
987
1004
1021
1038
1055
1072
1089
1106
1123
1140
1157
1174
1191
1208
1225
1242
1259
1276
1293
1310
1327
1344
1361
1378
1395
1412
Time (s)
Control
Observed Temperature Sensor 1
Observed Temperature Sensor 2
Reference


Temperature vs. Time Graph (Embedded Sensor)
Temperature (°C)
40
35
30
25
20
15
10
5
0
1
28
55
82
109
136
163
190
217
244
271
298
325
352
379
406
433
460
487
514
541
568
595
622
649
676
703
730
757
784
811
838
865
892
919
946
973
1000
1027
1054
1081
1108
1135
1162
1189
1216
1243
1270
1297
1324
1351
1378
1405
1432
1459
1486
1513
1540
1567
1594
1621
1648
1675
1702
1729
1756
1783
1810
1837
1864
1891
1918
1945
1972
1999
2026
2053
2080
2107
2134
2161
2188
2215
2242
2269
2296
2323
2350
2377
2404
2431
2458
2485
2512
2539
2566
2593
2620
2647
2674
Time (s)


Temperature vs. Time Graph (Lying on a Spine With Clothes)
Temperature (°C)
37
36
35
34
33
32
31
30
29
Time (s)
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239 246 253 260 267 274 281 288 295 302 309 316 323 330 337 344 351 358 365 372 379 386 393 400 407 414 421 428 435 442 449 456 463 470 477 484 491 498 505 512 519 526 533 540 547 554 561 568 575 582 589 596 603 610 617 624 631 638 645 652 659


Temperature vs. Time Graph (Lying on a Spine Without Clothes)
Temperature (°C)
36.5
36
35.5
35
34.5
34
33.5
33
Time (s)


Temperature vs. Time Graph (Lying on a Stomach With Clothes)
Temperature (°C)
37
36
35
34
33
32
31
Time (s)
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239 246 253 260 267 274 281 288 295 302 309 316 323 330 337 344 351 358 365 372 379 386 393 400 407 414 421 428 435 442 449 456 463 470 477 484 491 498 505 512 519 526 533 540 547 554 561 568 575 582 589 596 603 610 617 624 631 638 645 652 659


Temperature vs. Time Graph (Lying on a Stomach Without Clothes)
Temperature (°C)
37
36.5
36
35.5
35
34.5
34
33.5
33
32.5
32
Time (s)
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239 246 253 260 267 274 281 288 295 302 309 316 323 330 337 344 351 358 365 372 379 386 393 400 407 414 421 428 435 442 449 456 463 470 477 484 491 498 505 512 519 526 533 540 547 554 561 568 575 582 589 596 603 610 617 624 631 638 645 652