Training Neural Networks for Sensors

Team Members:
Vicki Moran (Fall Lead)
Henry Limm (Spring Lead)
Taylor Sloop
Will McDonald
Yaqub Mahsud (Spring Jr)
Maxime Vienne (Fall FE)

Liaisons:
Dr. David Garrett
Atul Gupta
Dr. Sean McGregor

Advisor:
Prof. David Harris

Team Members and Primary Focuses

Henry

HMC Senior
Spring Team Leader

Firmware Development

Will

HMC Senior

Demo and Network

Taylor

HMC Senior

Data Collection

Vicki

HMC Senior
Fall Team Leader

Board Design

Yaqub

HMC Junior

Network Training

Harvey Mudd College Clinic Program

"I gained the idea that engineering was like dancing; you don't learn it in a darkened lecture hall watching slides: you learn it by getting out on the dance floor and having your toes stepped on."

- Jack Alford, Professor of Engineering Emeritus, Cofounder of the Engineering Clinic, Harvey Mudd College 1963

- Teams of four to five juniors and seniors
- Professional design and development projects for industry sponsors
- Objective: to produce useful results on an open-ended authentic project to the sponsor's satisfaction within the constraints of time and budget

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Problem Statement

The Syntiant-HMC Clinic team will demonstrate the versatility and power efficiency of the Syntiant NDP101 chip by designing a battery-powered application that receives live data from sensor(s) and uses a neural network running on the chip to detect significant events.

Interpreting our Problem Statement

- Microphones
- Wakewords (“Alexa”)
- Small/low-power electronics

Interpreting our Problem Statement

- Microphones
- Wakewords (“Alexa”)
- Small/low-power electronics

→

- Inertial Measurement Unit
- Unique motions and gestures
- Small and low-power smartwatch

Design Alternatives

Application	Be always-on and battery powered	Be an application of machine learning	Be demonstrable and tangible	Be feasible to collect and use data	Be feasible to implement	Be marketable in time and volume
Identify dead pointe shoes	3	3	Constrained by time and shoe dependencies (1)	Limited by existing data and minimal access to many pointe dancers (2)	3	Restricted to niche ballet market (2)
Identify gestures	**3**	**3**	**3**	**3**	**3**	**3**
Identify body movements	3	3	3	3	3	Implemented previously in large battery systems (2)

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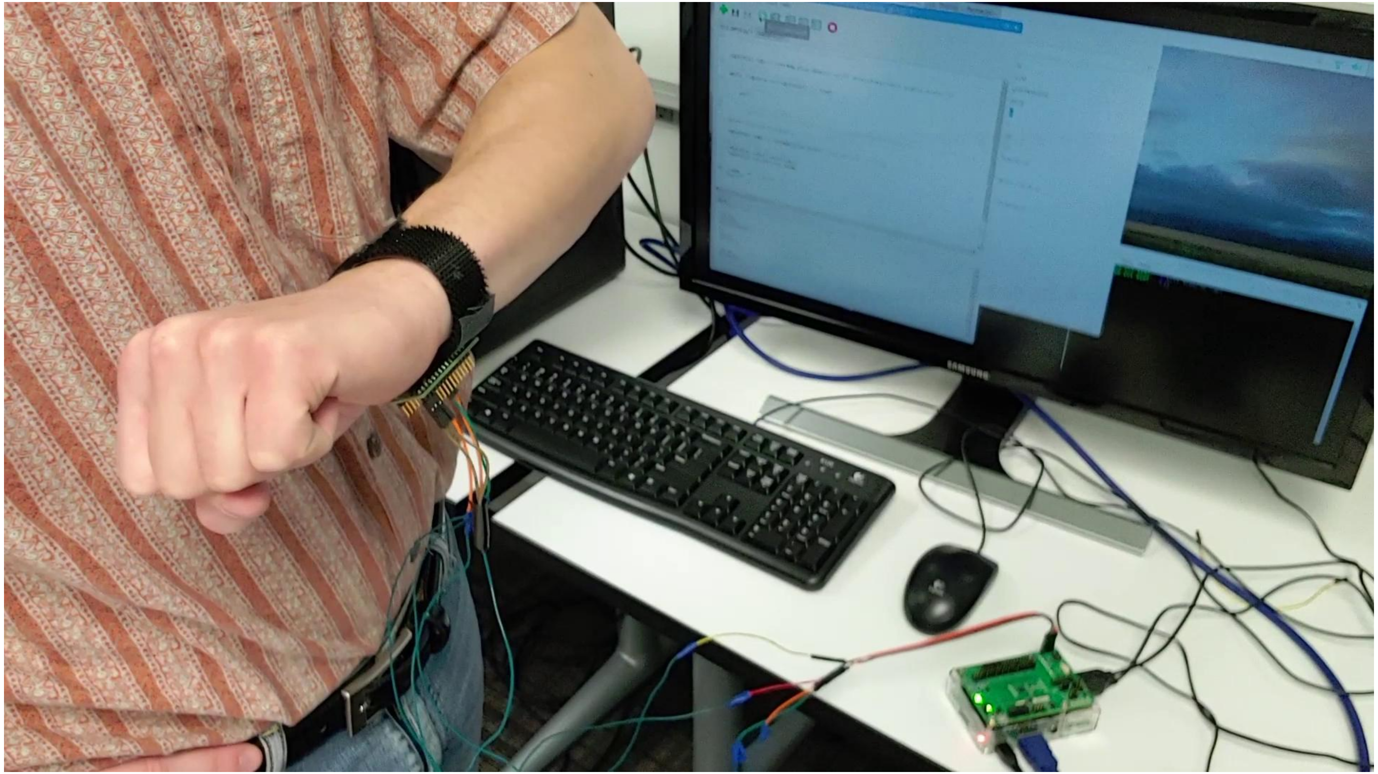
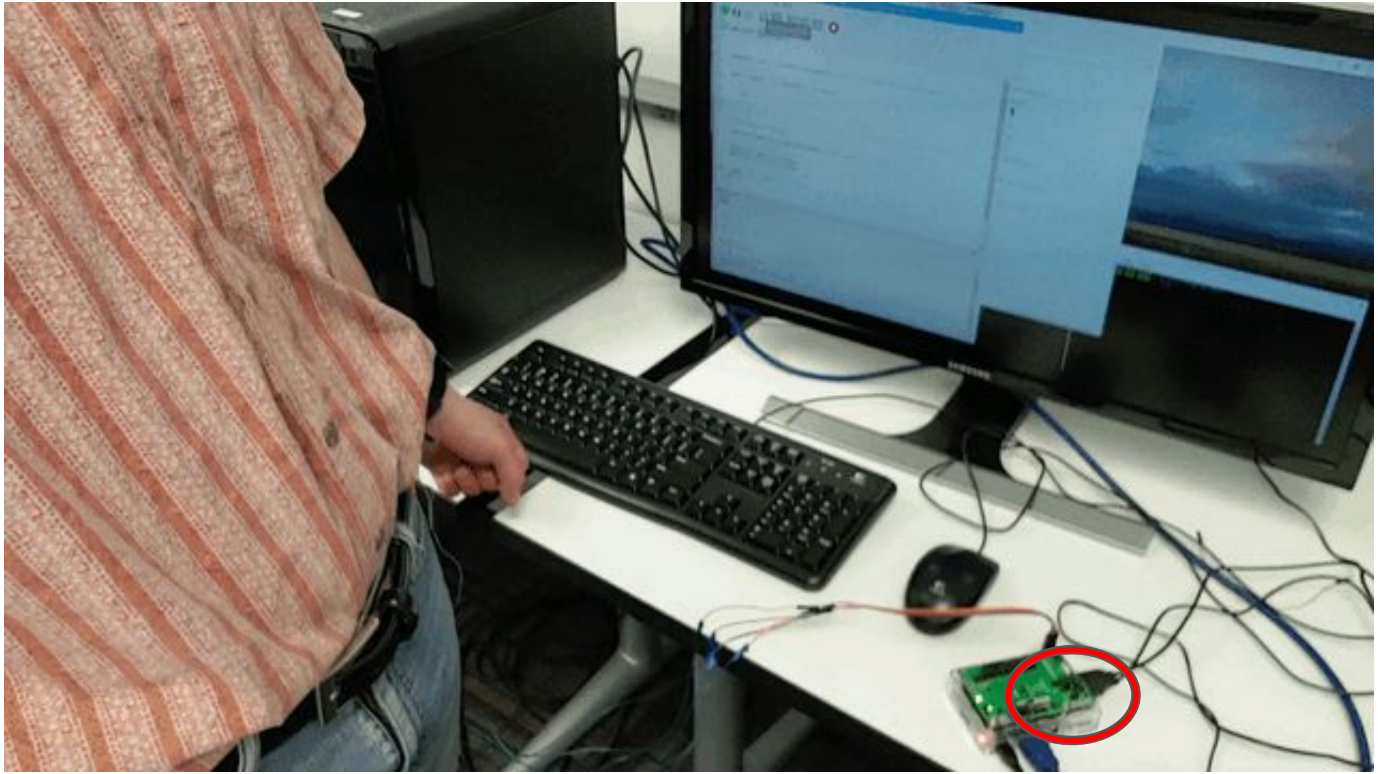
Wrist-Based Gestures

- Time-checking
- Pronating
- Supinating

Watch-Checking Demonstration



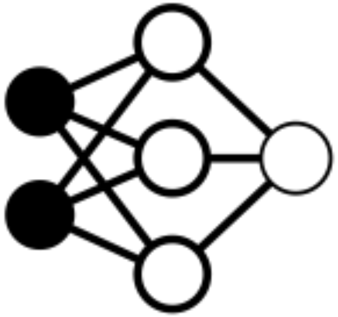
Watch-Checking Demonstration



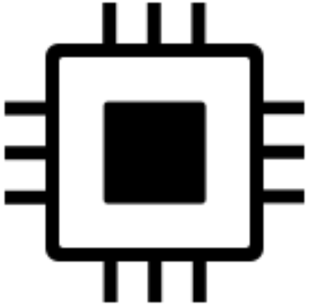
Prototype Breakdown

Data Collection

Neural Network Training



NDP101 Demonstration



Printed Circuit Board Design

Data Collection

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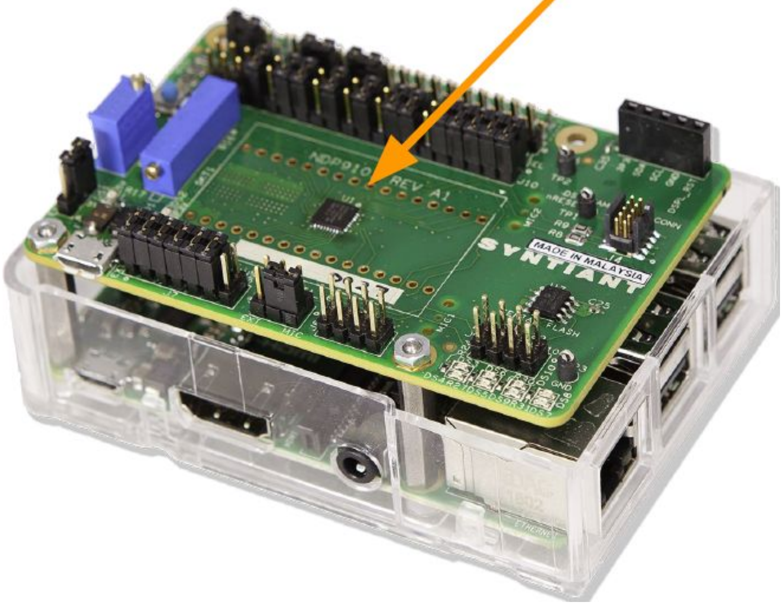
Data Collection Hardware

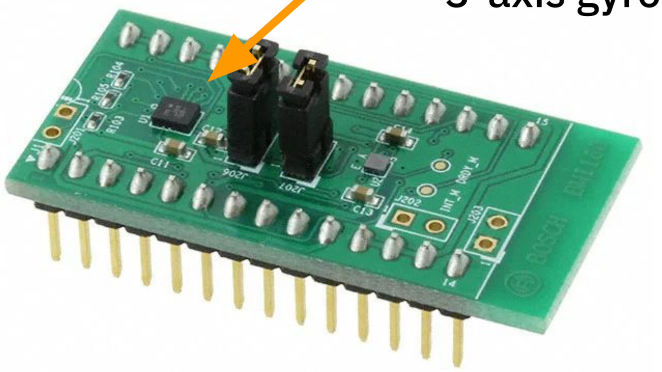
NDP101



BMI160

3-axis accelerometer

3-axis gyroscope



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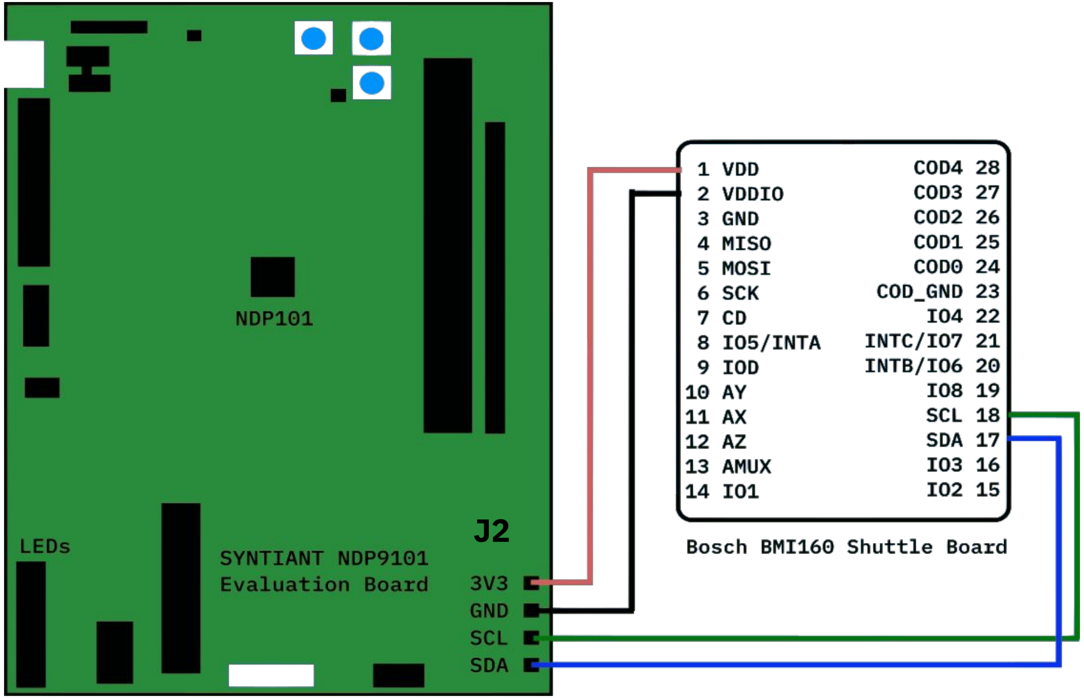
Physical System Schematic



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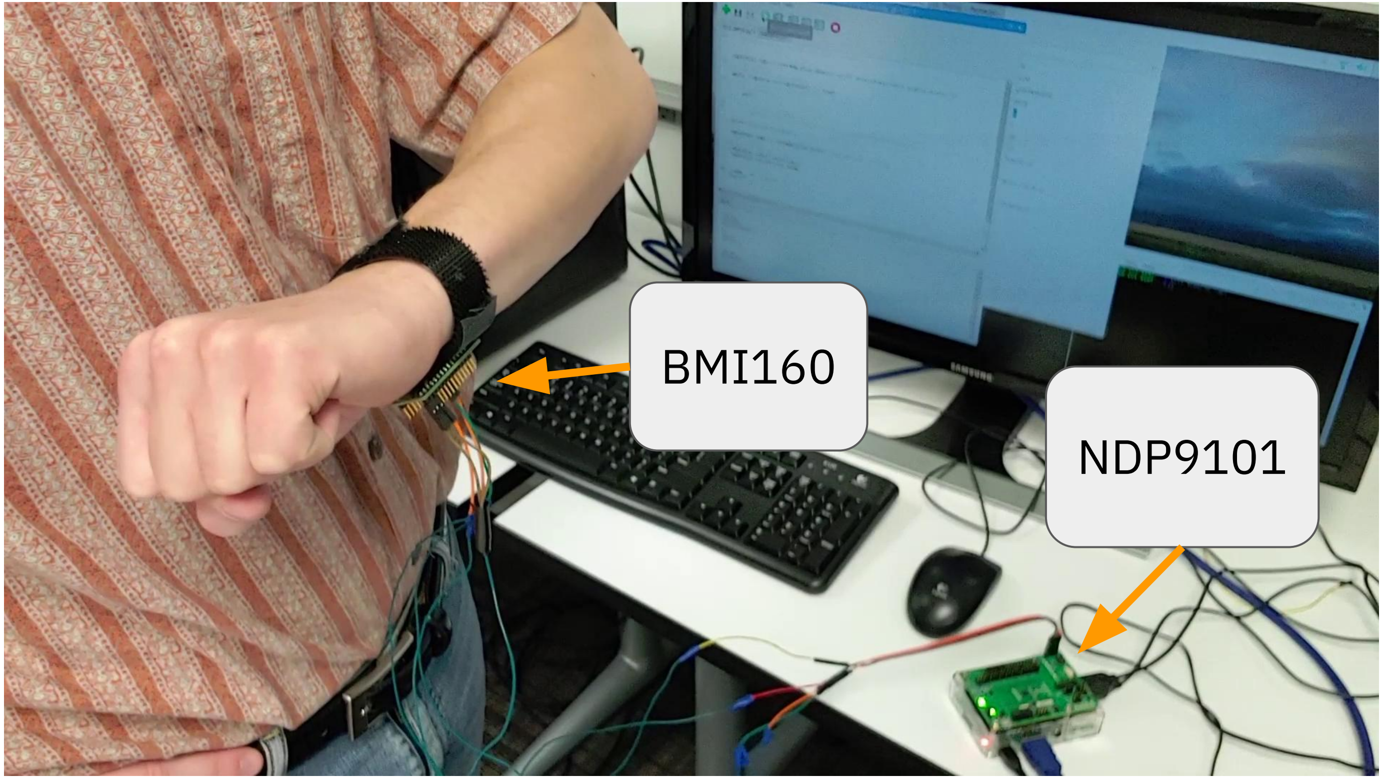
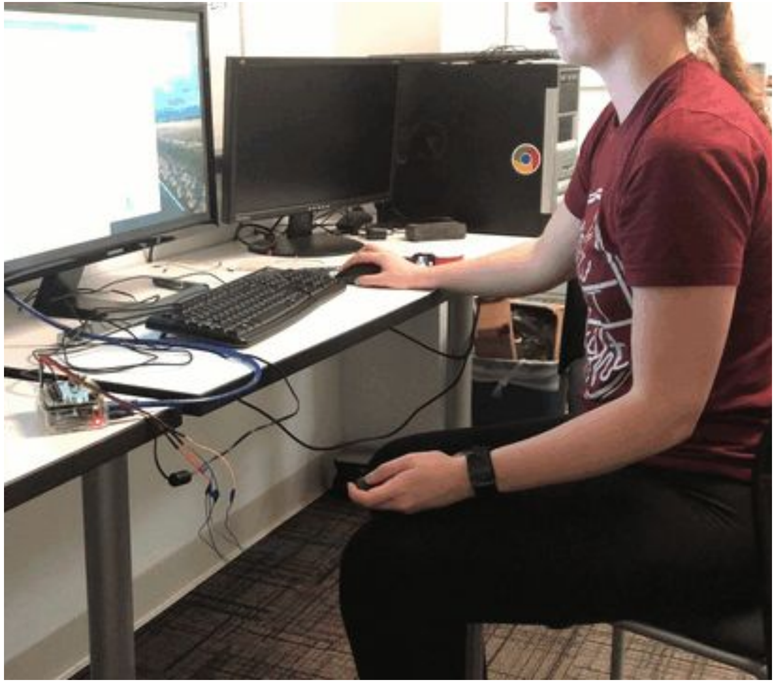
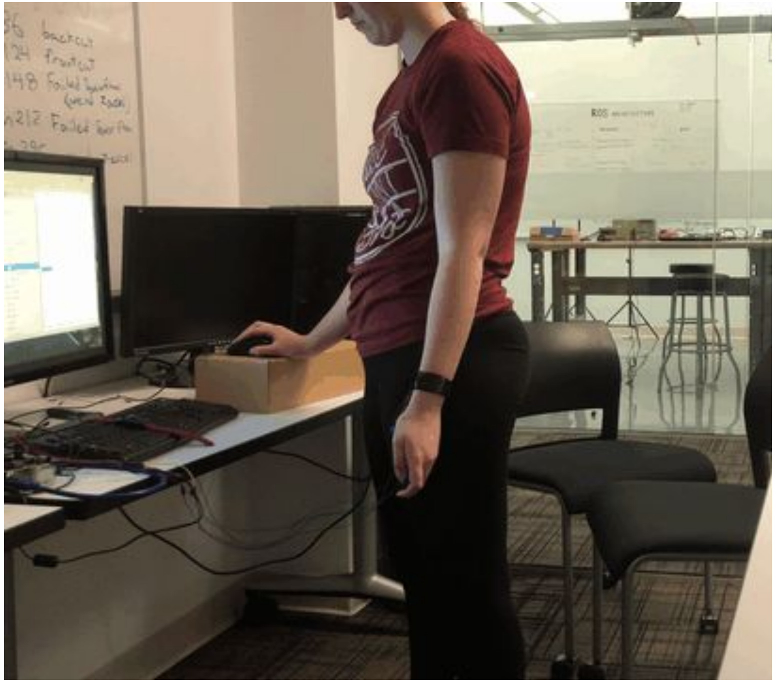
Demo and Data Collection System



Data Collection Involves Multiple Gestures





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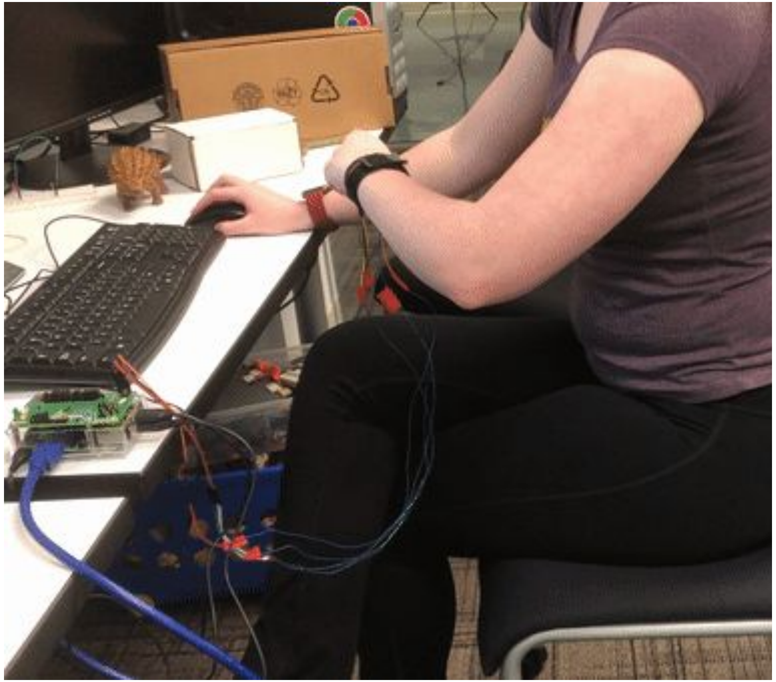
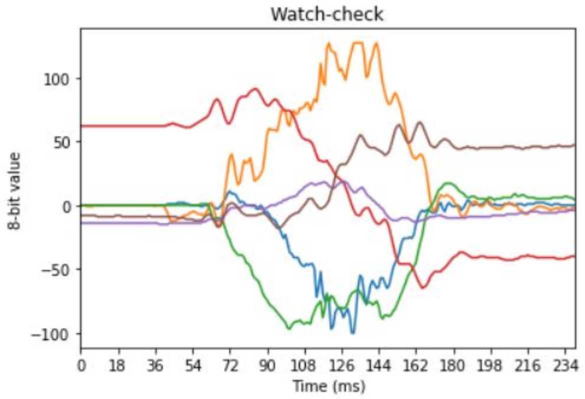
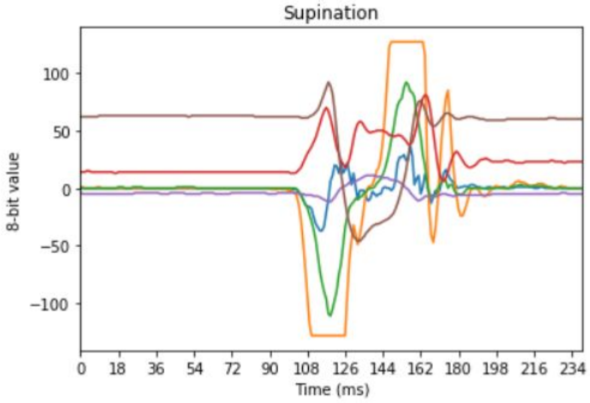
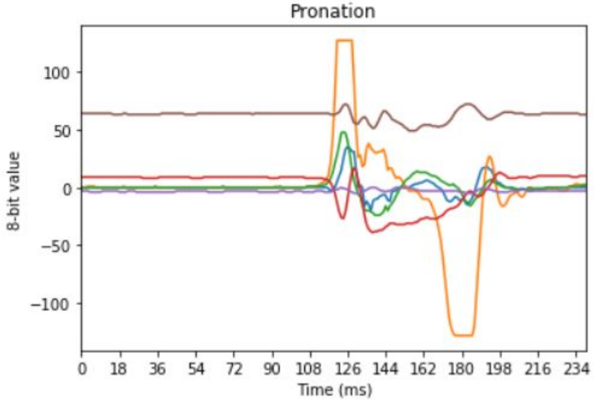
Additional Gestures



Typical Data Instances







- 2.4 seconds of BMI160 data sampled at 100 Hz.
- 240 sampled values on each axis.

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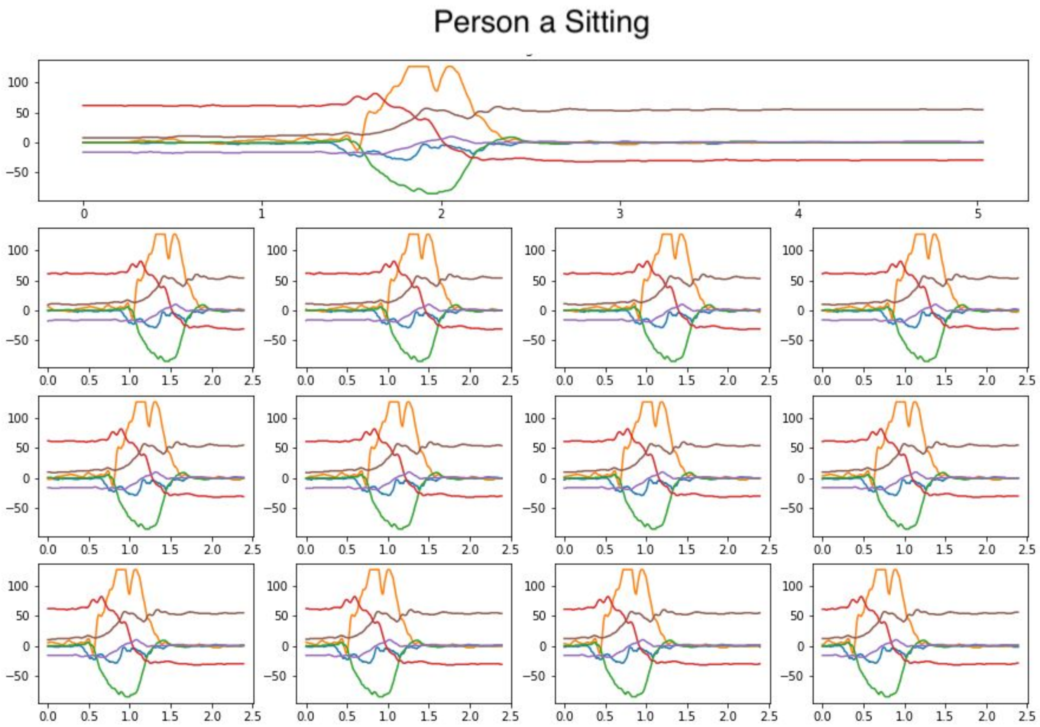
Data Augmentation



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Data Collection Composition

Large Scale Collection

- 26 participants and 2 team members
- 10 sitting watch-checking, 10 standing watch-checking, 10 supination, 10 pronation per person
- ~16 augmented samples per original sample

Previous Data Collection

- 300 watch checking by team members

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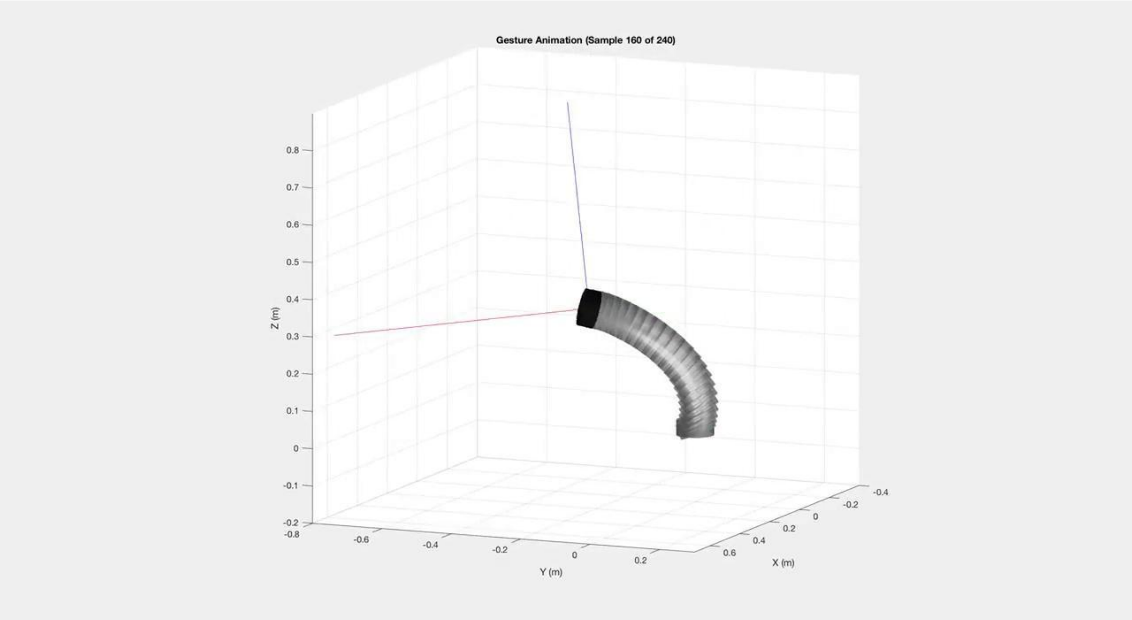
Data Visualization



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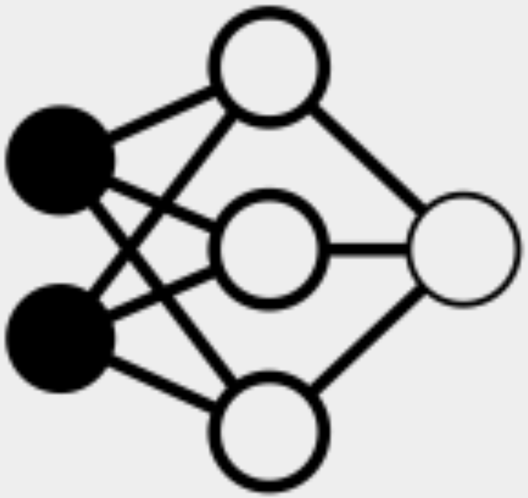
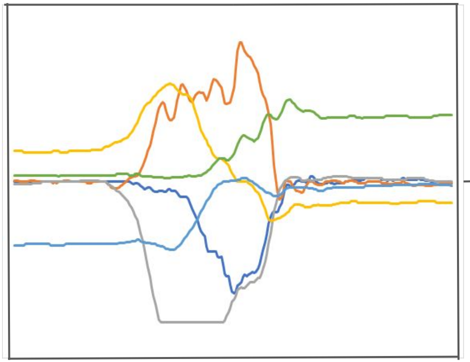
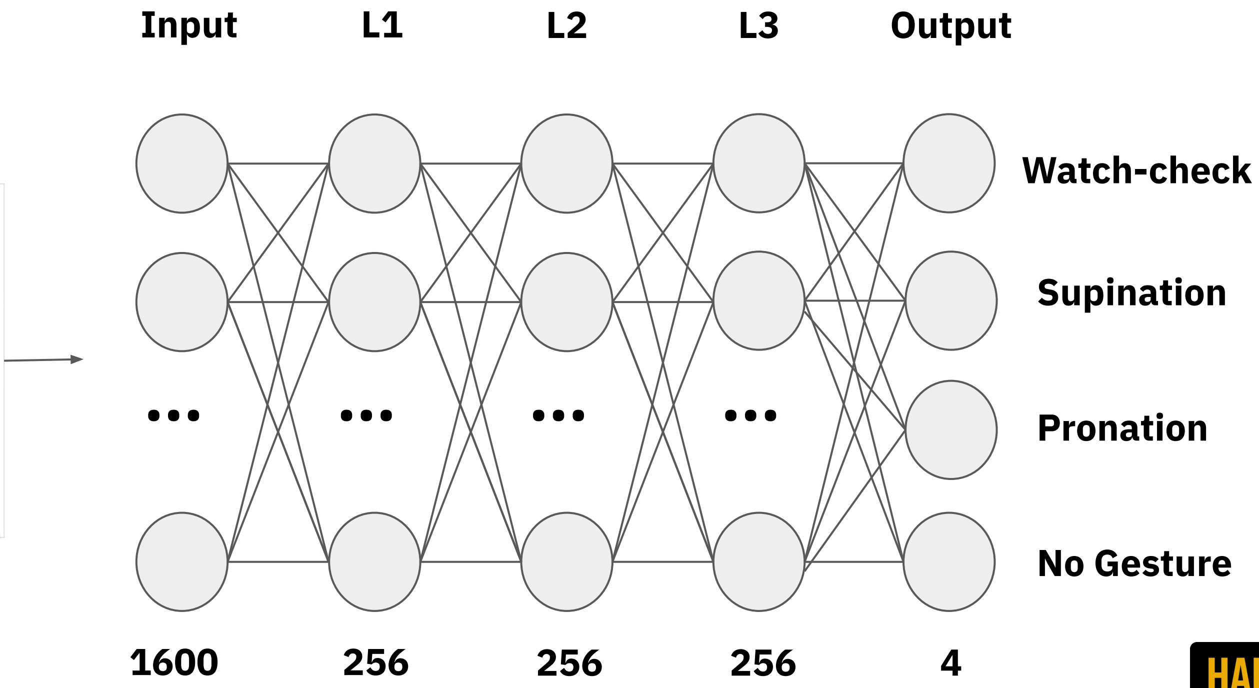
Network Training



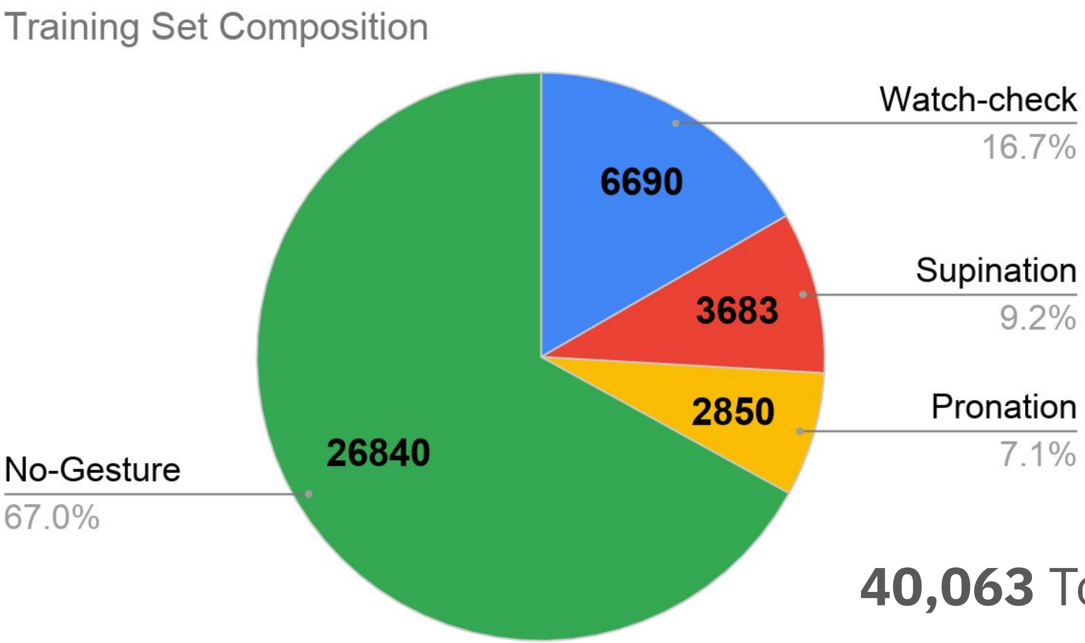
Network Architecture

Data Instance





Dataset Composition



40,063 Total Data Instances

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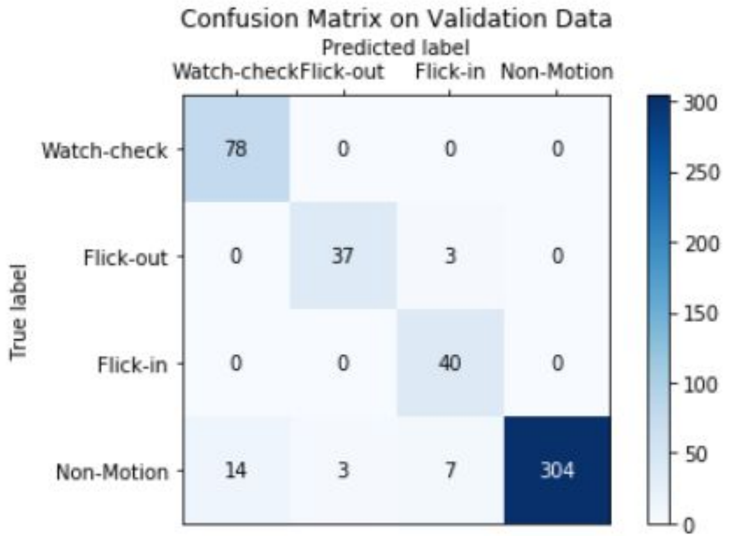
Network Performance

Validation Accuracy	***94.44%***
Test Accuracy	**96.86%**
Precision	**85.16%**
Recall	**100%**
False Activation Rate	**237/day**



Partition	Watch-check	Supination	Pronation	No-Gesture	Total
Val. Total	78	40	40	328	486

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Effect of Time-Shifting

Implementing time-shifted data increased validation accuracy by 2%

	Time-Shifting	No Time-Shifting
Validation Accuracy	94.44%	92.64%

Partition	Watch-check	Supination	Pronation	No-Gesture	Total
Val. Total	78	40	40	328	486

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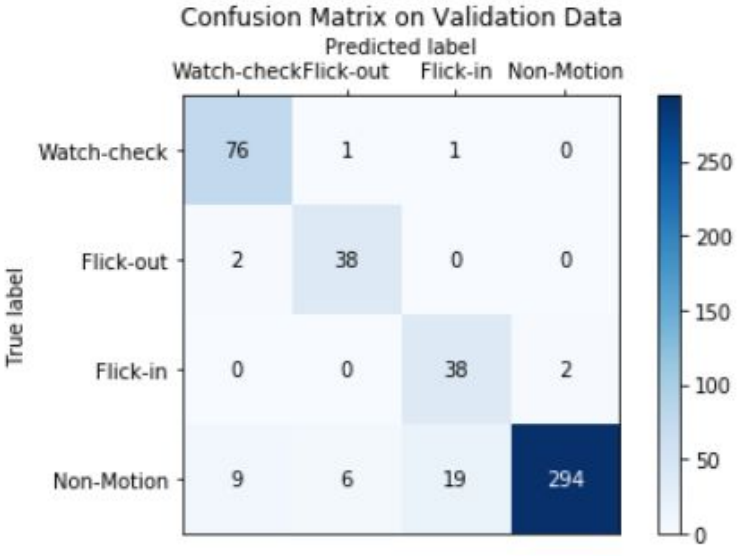
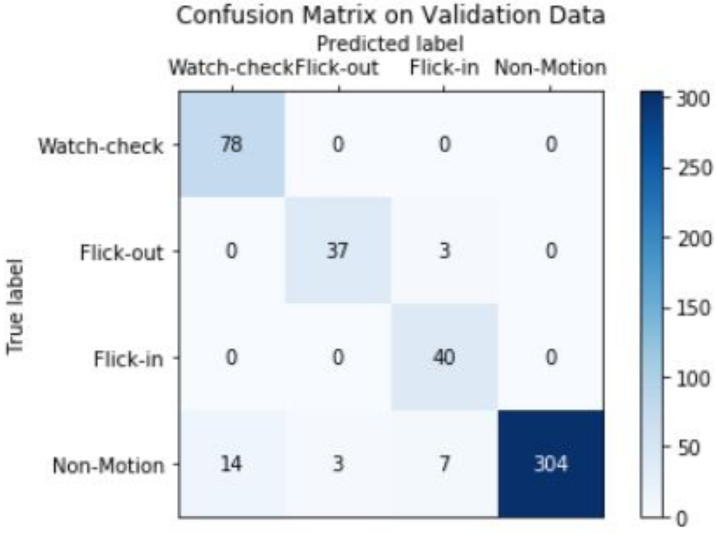
Effect of Time-Shifting

Implementing time-shifted data increased validation accuracy by 1.8%.

No-Time Shifting (92.64%)



Time-Shifting (94.44%)



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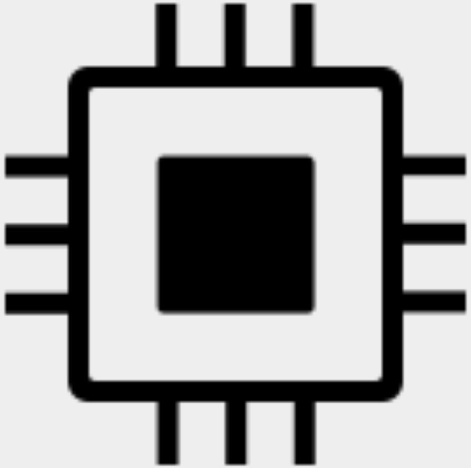
NDP101 Demo



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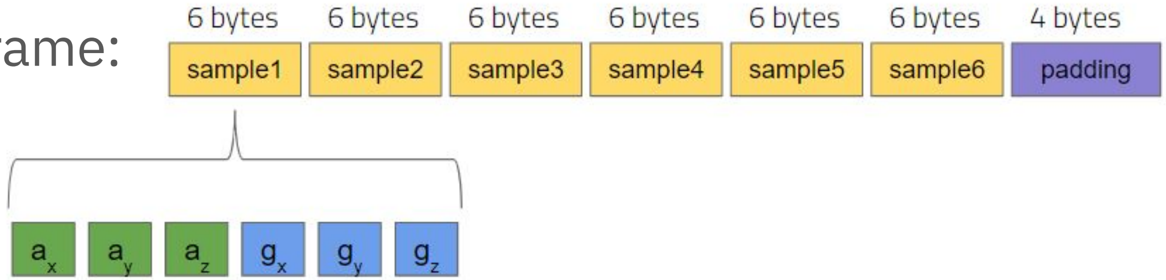
Framing for Input window

Each Data Instance is 1600 bytes - consider as 40 frames of 40 bytes.

A frame:



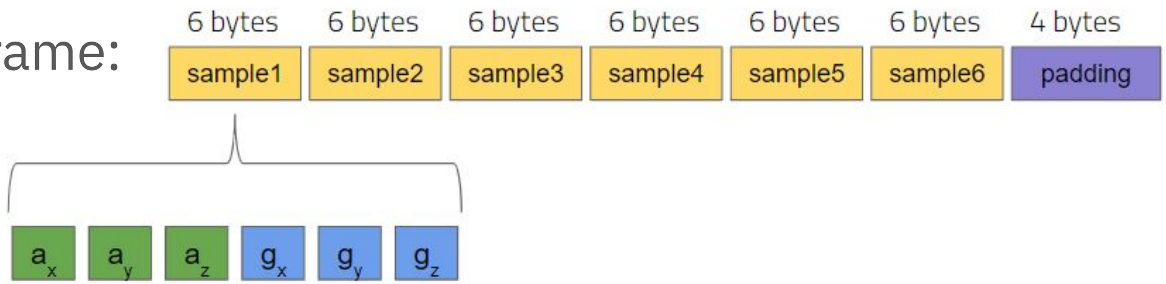
All 6 axes sampled from the BMI160 every 10 milliseconds.

Each frame contains 60 milliseconds of consecutive data.

Framing for Input window

Each Data Instance is 1600 bytes - consider as 40 frames of 40 bytes.

A frame:



A full window:

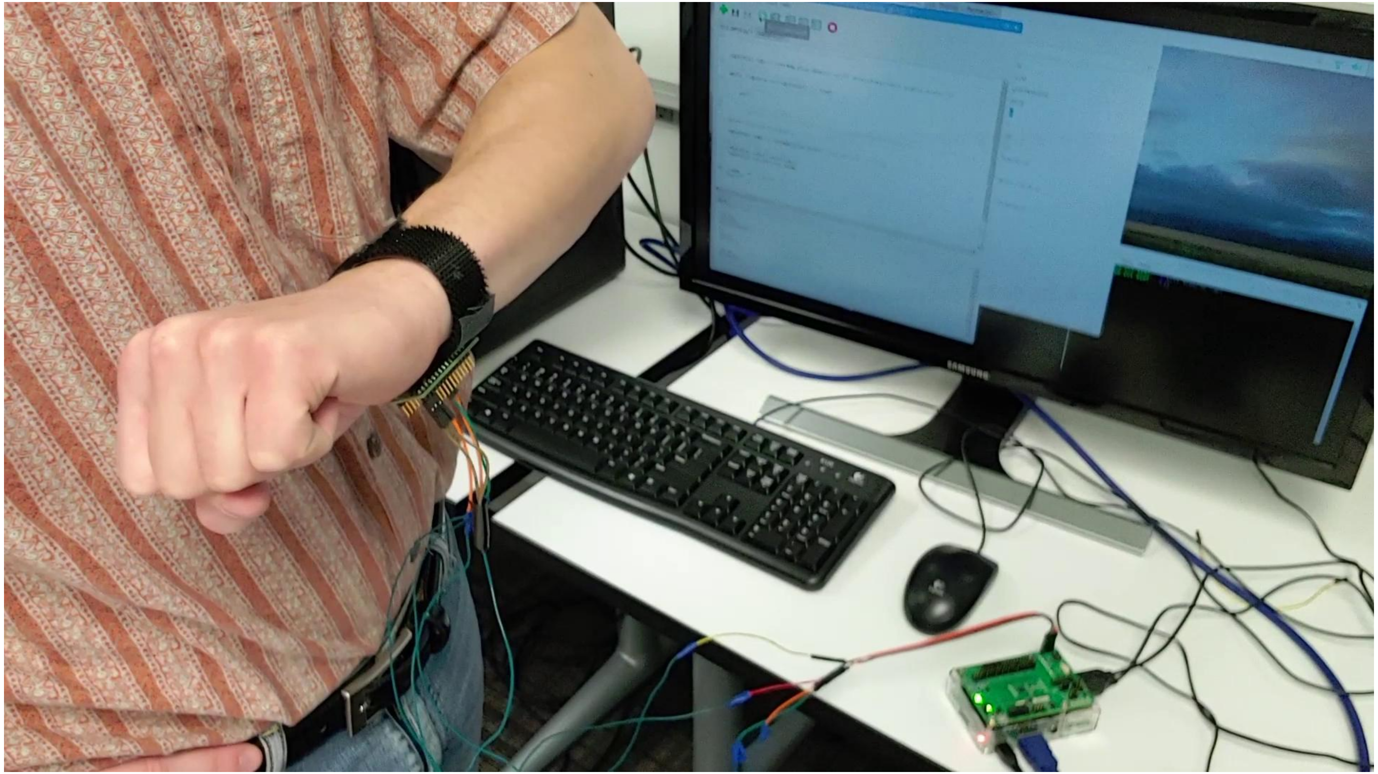
(40 frames, 1600 bytes)

Demo Considerations

Development of the Demo halted prematurely due to technical freeze.

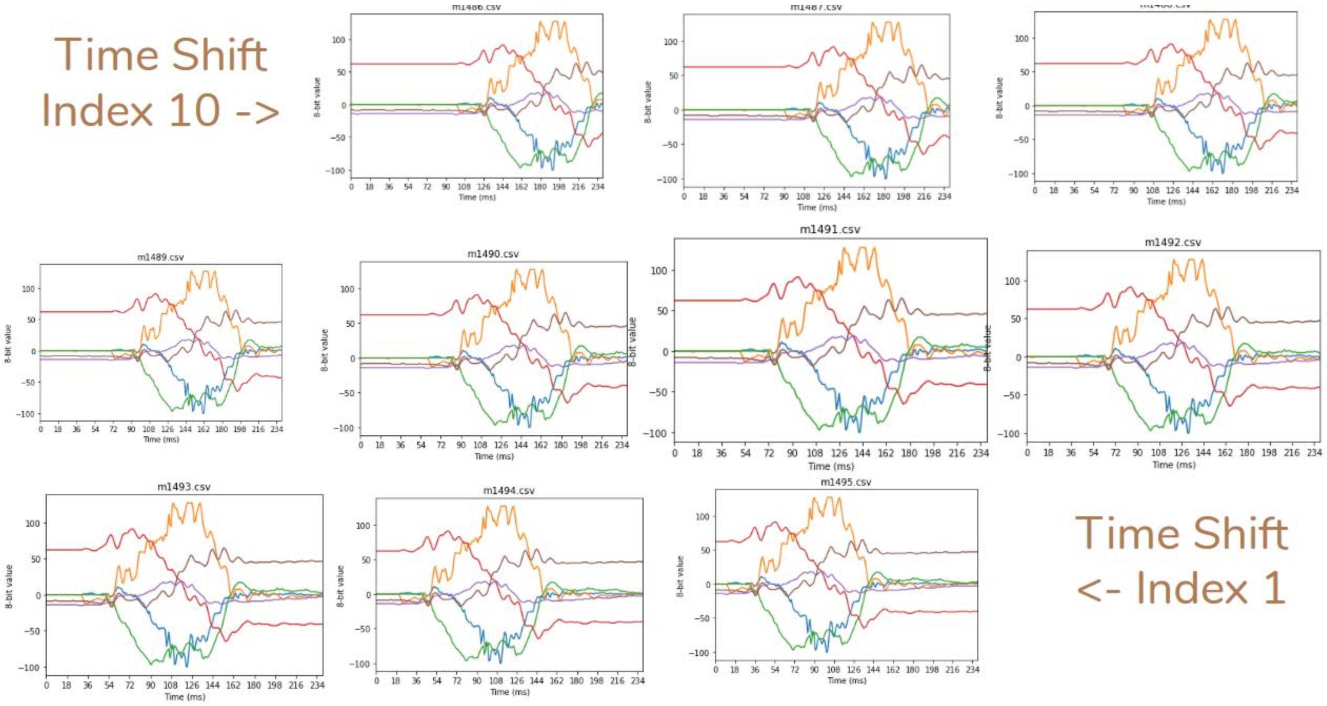
- Implement and Test Current Network on NDP101
    - Compare test accuracy on the NDP101 to test accuracy on Tensorflow
- Compute actual false activation rate (FAR)
- Reduce latency between gesture and LED response

Watch-Checking Demonstration



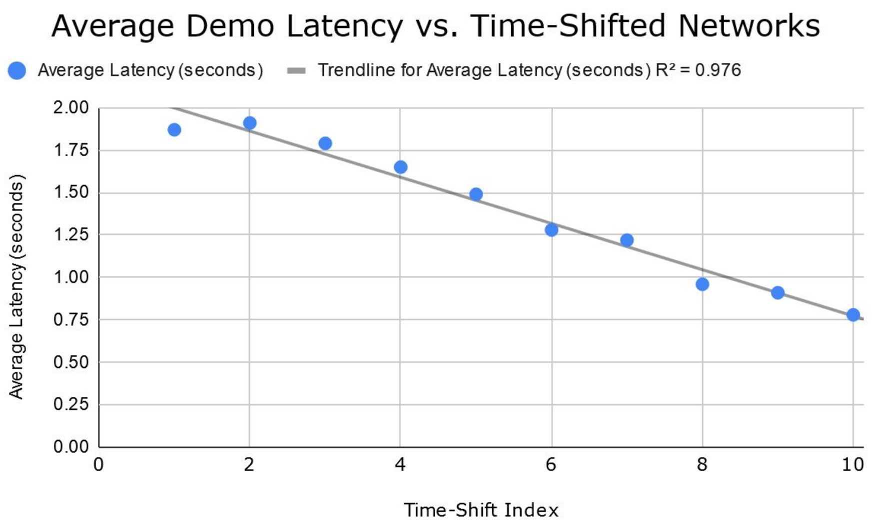
Demo Latency Experiment

Assess latency of networks with gestures at each of these positions within the NDP101 input window



Demo Latency Experiment

Including time-shifted data potentially reduces latency to 0.78 seconds



Time-Shift Index	Average Latency (seconds)
1	1.87
2	1.91
3	1.79
4	1.65
5	1.49
6	1.28
7	1.22
8	0.96
9	0.91
10	0.78

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Demo Latency Experiment

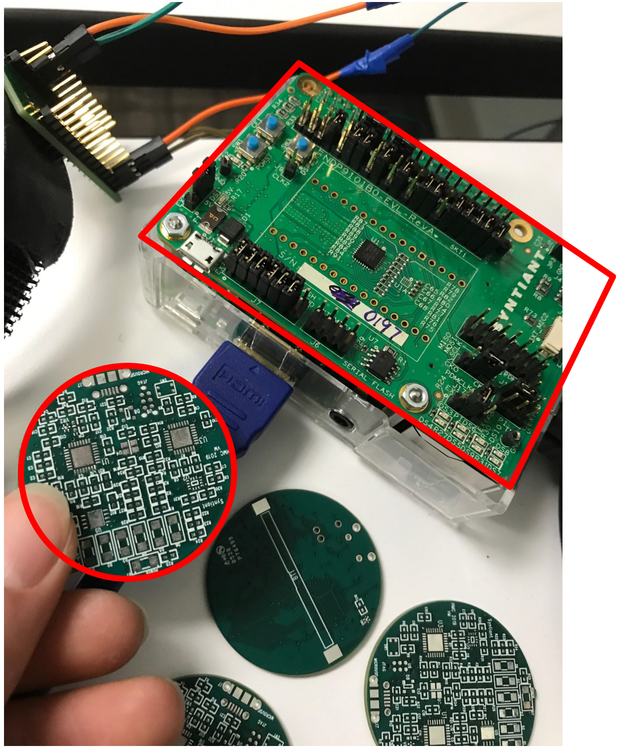
Potential cause of remaining latency:

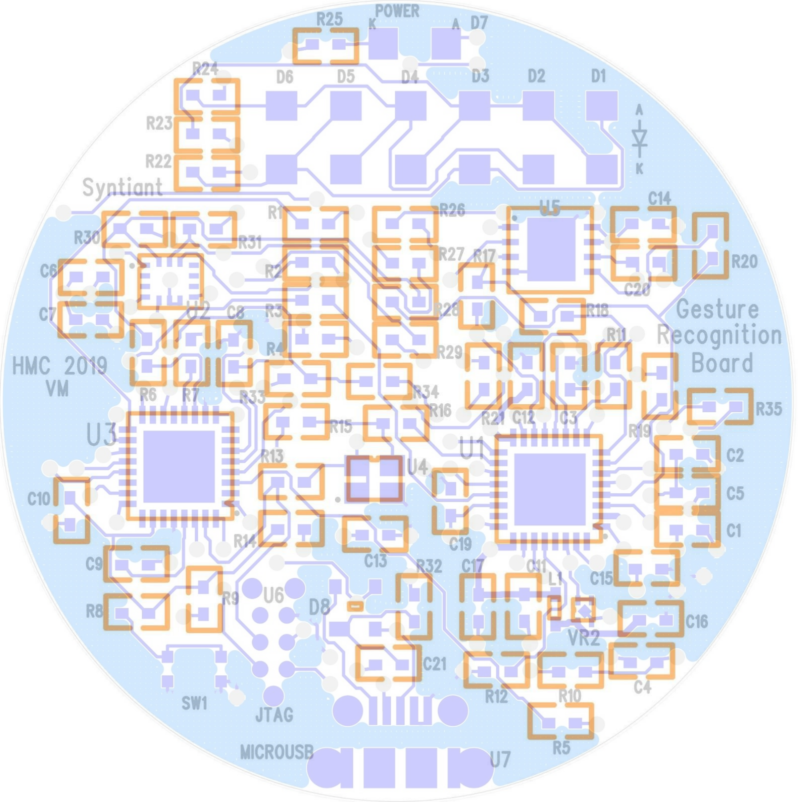
- Frames must be sent to the NDP101 every 60 milliseconds.
- Tested demo iteration sends a new frame every 80 milliseconds.
- Excess 20ms * 40 frames = 800ms
- For a full window, ~.8 seconds latency

Time-Shift Index	Average Latency (seconds)
1	1.87
2	1.91
3	1.79
4	1.65
5	1.49
6	1.28
7	1.22
8	0.96
9	0.91
10	0.78

PCB Design

Benefits of a Custom Printed Circuit Board





1.5”

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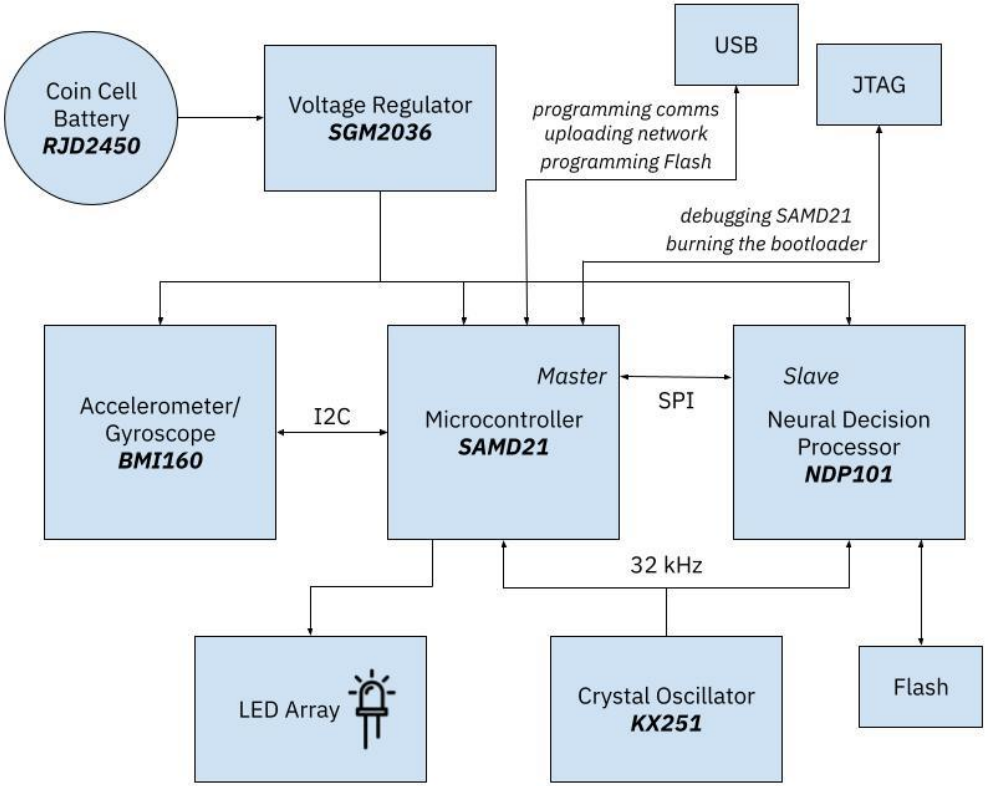
Implementation of the Board



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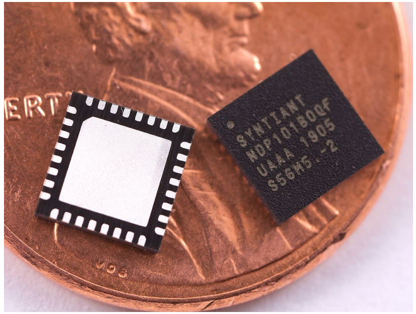
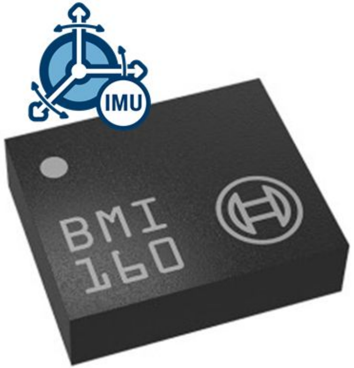
Components Consume Minimal Power



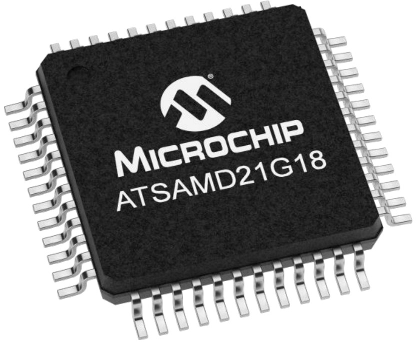
Neural Network Chip *(NDP101)*

60 µA



Accelerometer/ Gyroscope *(BMI160)*

925 µA



Microprocessor *(ATSAMD21)*

2.04 mA

Battery *(RJD2450)*

200mAh

Battery Life:

65.4 hours

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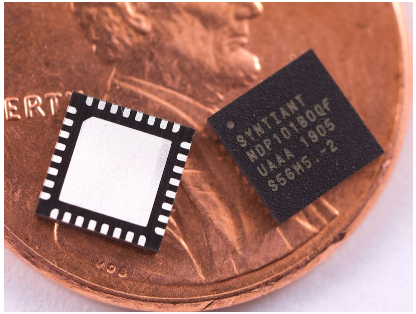
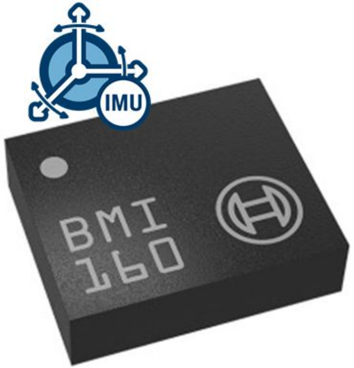
Components Consume Minimal Power



Neural Network Chip *(NDP101)*

60 µA



Accelerometer/ Gyroscope *(BMI160)*

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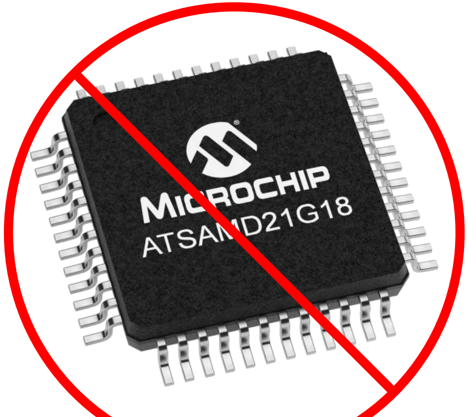

Microprocessor *(ATSAMD21)*

2.04 mA

Battery *(RJD2450)*

200mAh

Battery Life:

196 hours

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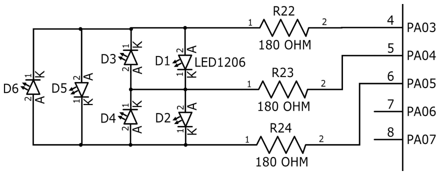
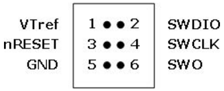
Other Components Enable Additional Features



Charlieplexed LED array

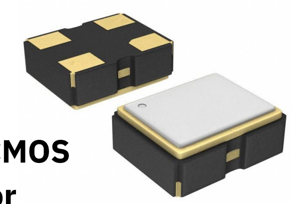
To indicate up to 64 motions



6 pin JTAG

To program and debug the microcontroller

32kHz CMOS oscillator



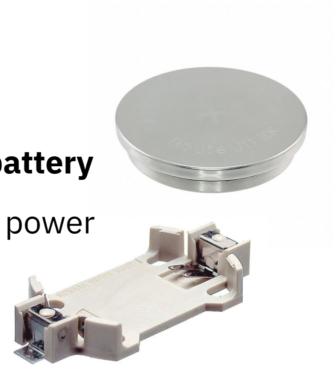
To generate reference clocking

LDO regulators

To regulate 3.3V and 0.9V supplies

Coin cell battery

To provide power



64 Mb serial flash memory

To store the neural network

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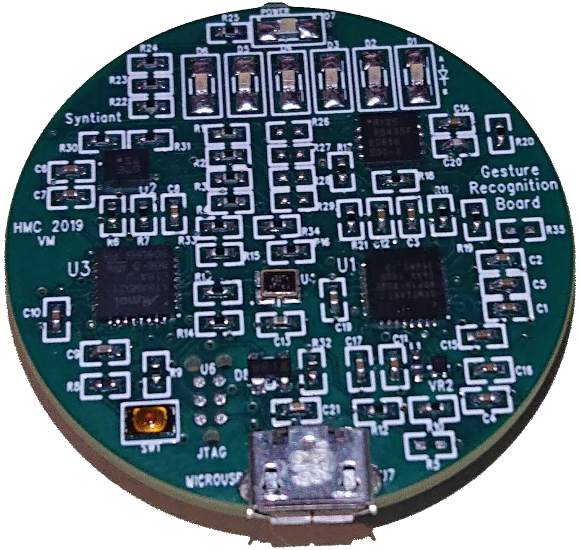
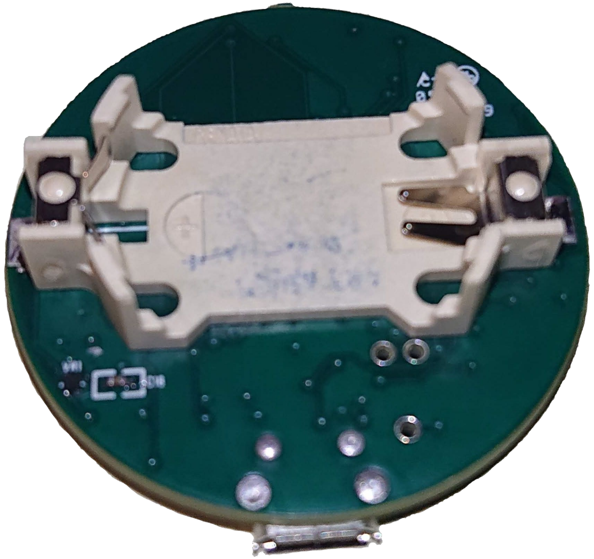
Assembled Board





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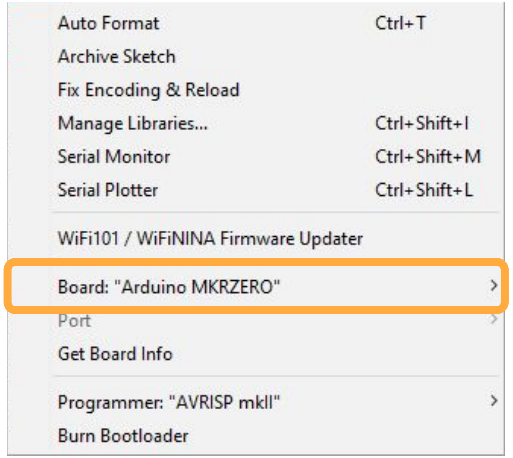
Current Progress

- Arduino Bootloader loaded
- Can print to USB serial
- Can blink LEDs
- Cannot use SPI to NDP101




```
Serial.println("Hello World");
```

```
digitalWrite(LED_PIN_A, HIGH);
digitalWrite(LED_PIN_B, LOW);
```

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Conclusion

Deliverables

Data:

- Original Dataset
- Augmented Dataset
- Data Description File
- Logging scripts

Network:

- Train_accelerometer.py

Demonstration:

- Demo scripts
- GRB firmware

Hardware:

- Raspberry Pis
- NDP9101s
- BMI160s
- Gesture Recognition Boards
- Spare parts for the GRB

Future Work

- Complete board bringup by fully implementing firmware
- Test network features on completed board — latency, false activation etc. — and tune network as necessary
- Expand data collection to more people

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Thanks for Your Time!

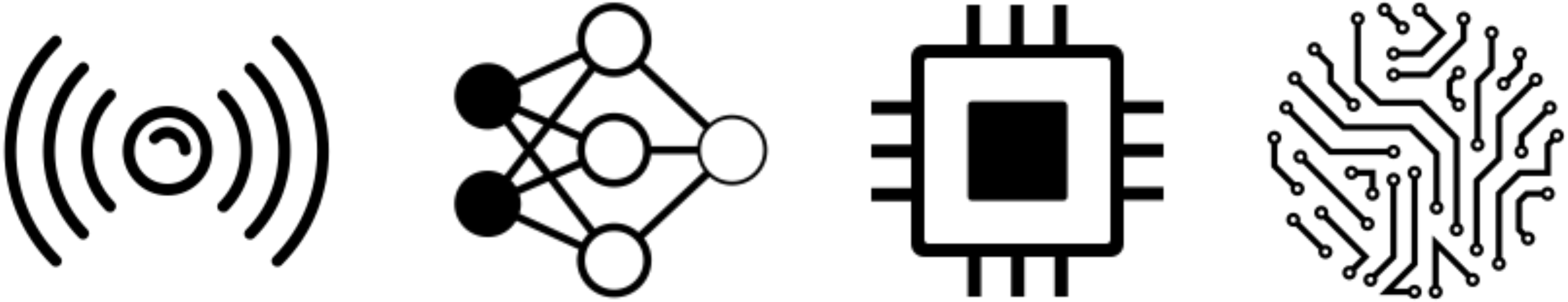
Special thanks to

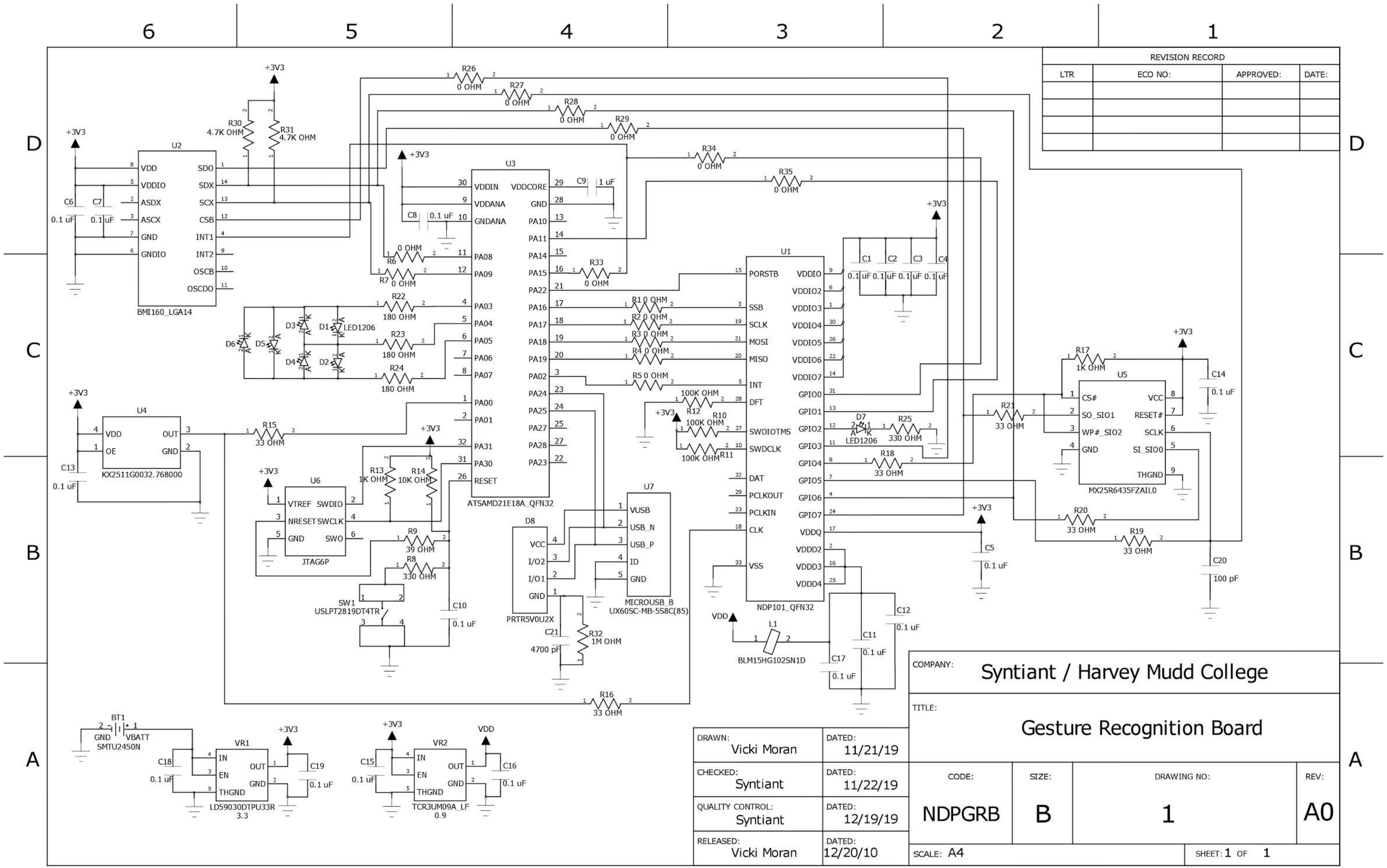
Jay Cordaro and Yao Gao (Board Design Review)

Paul Williams (Board Assembler)

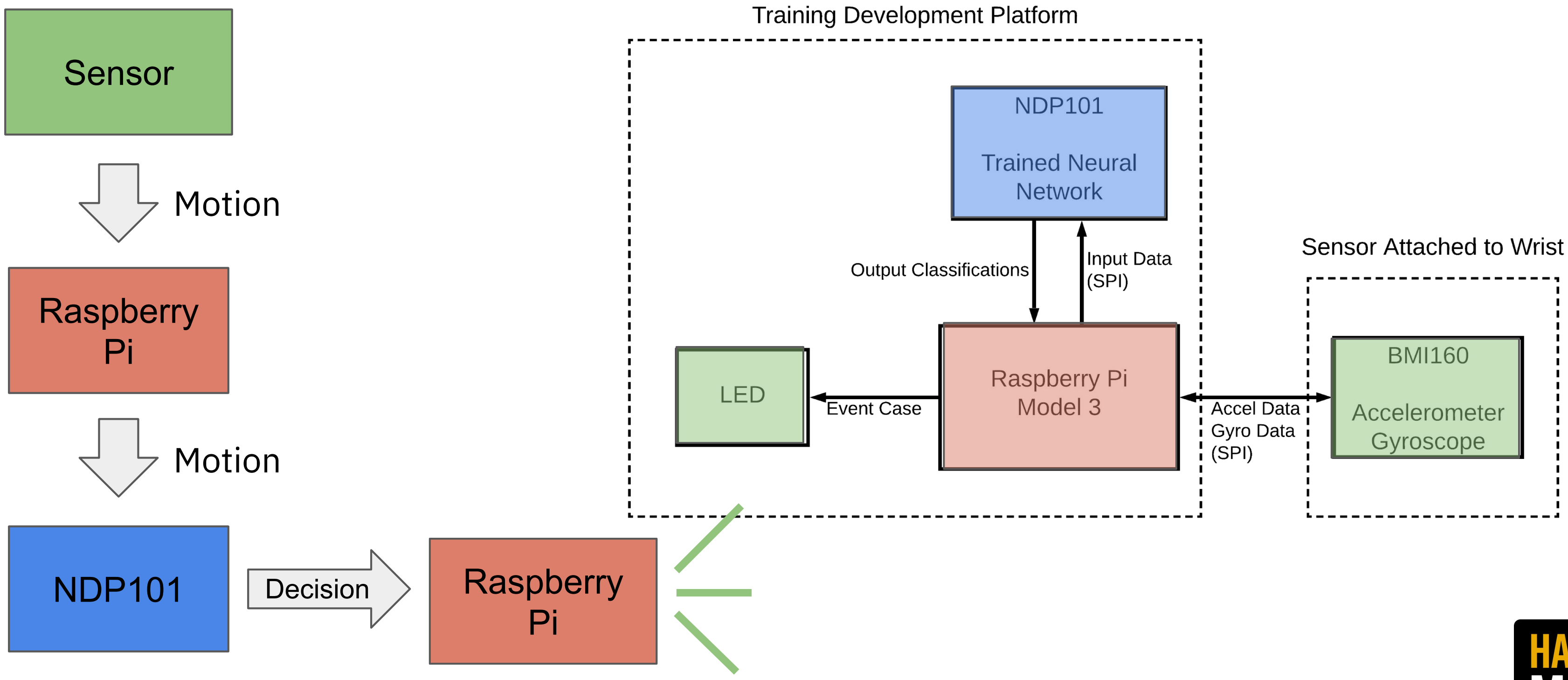
Kaveh Pezeshki (HMC Engineering Server Admin)

Questions?




REVISION RECORD
LTR | ECO NO: | APPROVED: | DATE:
U2 BMI160_LGA14
U3 ATSAMD21E18A_QFN32
U1 NDP101_QFN32
U4 KX2511G0032.768000
U5 MX25R6435FZAIL0
U6 JTAG6P
U7 MICROUSB_B UX60SC-MB-5S8C(85)
D8 PRTR5V0U2X
SW1 USLPT2819DT4TR
L1 BLM15HG102SN1D
BT1 SMTU2450N
VR1 LD59030DTPU33R 3.3
VR2 TCR3UM09A_LF 0.9
+3V3
VDD
COMPANY: Syntiant / Harvey Mudd College
TITLE: Gesture Recognition Board
DRAWN: Vicki Moran
DATED: 11/21/19
CHECKED: Syntiant
DATED: 11/22/19
QUALITY CONTROL: Syntiant
DATED: 12/19/19
RELEASED: Vicki Moran
DATED: 12/20/10
CODE: NDPGRB
SIZE: B
DRAWING NO: 1
REV: A0
SCALE: A4
SHEET: 1 OF 1

How the Prototype Hardware Works



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Current Prototype Layout

NDP9101: Training Development Platform