Smart Tennis Racket with Shot Recognition Capability

Hardware Architectures for Embedded and Edge AI

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POLITECNICO DI MILANO

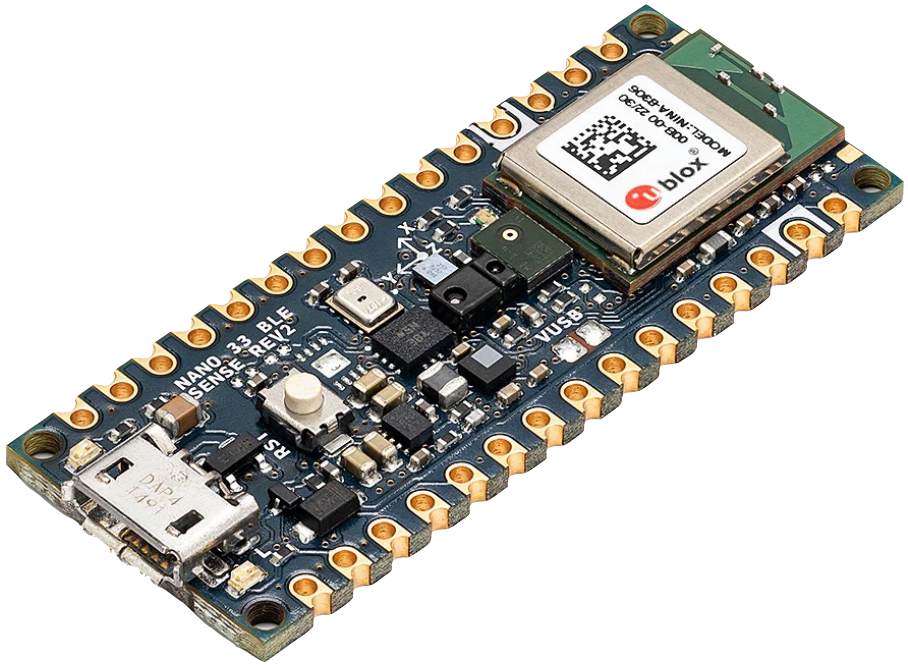
A tennis tracker

- Compact and lightweight tracker
- Detects 3 different tennis shots
- Battery powered
- Uses Bluetooth® Low Energy for data transmission

Hardware and Firmware

Hardware

- Arduino® Nano BLE sense rev.2 board
- Nordic® Semiconductor nRF52840 microcontroller
- Bosch BMI270 Inertial Monitoring Unit



Firmware: performance targets

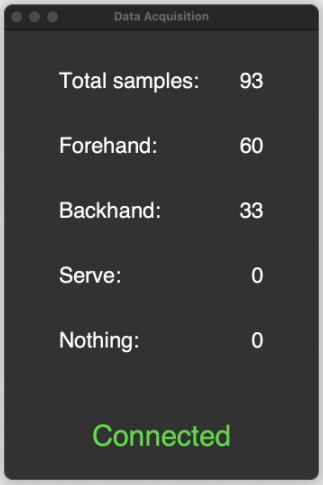
- Data acquisition window up to 10 seconds
- 3ms data rate (≈ 333 Hz)
- BLE data transmission lower than a couple of seconds

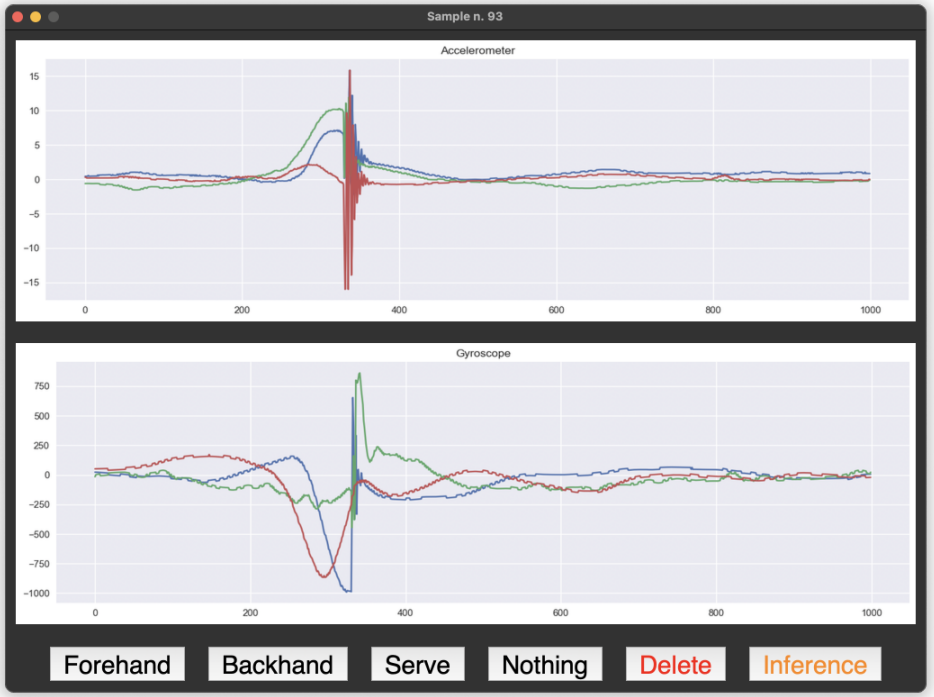
Firmware: libraries

- Custom Hardware Timers library
- Arduino BMI270 library
- ArduinoBLE library

Data Acquisition

Data Acquisition software

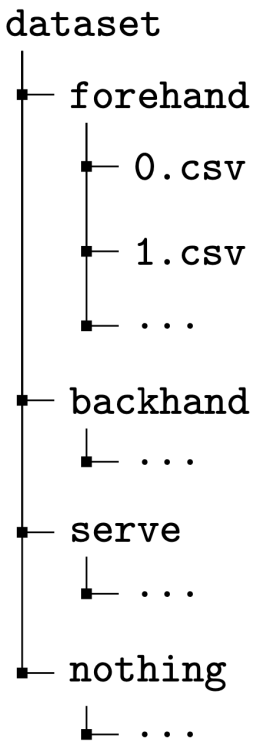




- Custom acquisition software
- Custom GUI
- Samples received through Bluetooth
- Instant samples labelling

Dataset

- 544 shots acquired
- 3 different players
- 3 seconds window
- Different racket orientations
- Each shot stored in a CSV file

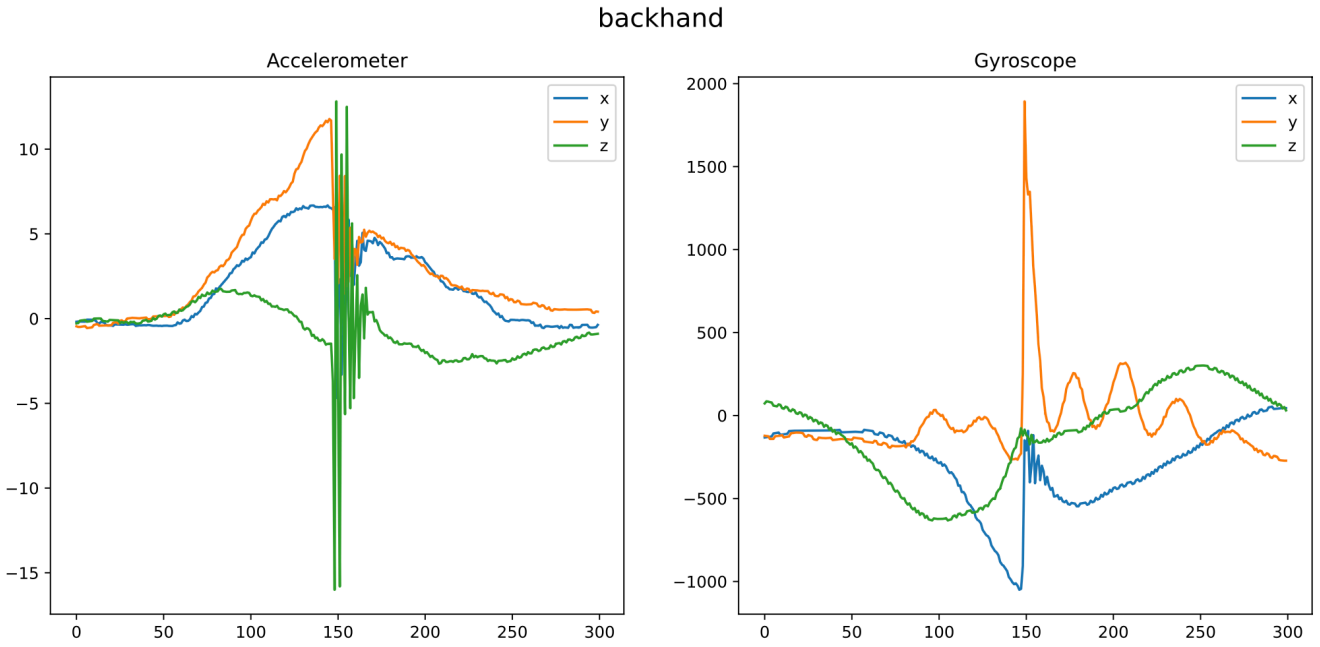



```
accX,accY,accZ,gyrX,gyrY,gyrZ
-0.065429,-0.778808,0.684570,-56.945800,-41.198730,5.249023
-0.067871,-0.781738,0.581054,-57.434082,-43.640136,5.126953
-0.066894,-0.783691,0.586425,-58.288574,-46.142578,4.882812
...
```

Model

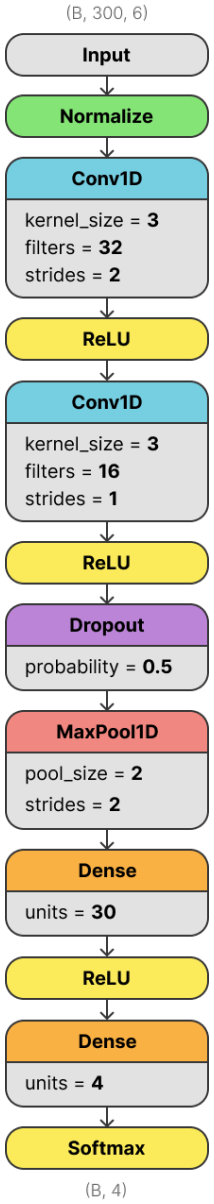
Pre-processing

- Crop 300 measurements centered in accelerometer spike (~1 sec window)
- Data standardization



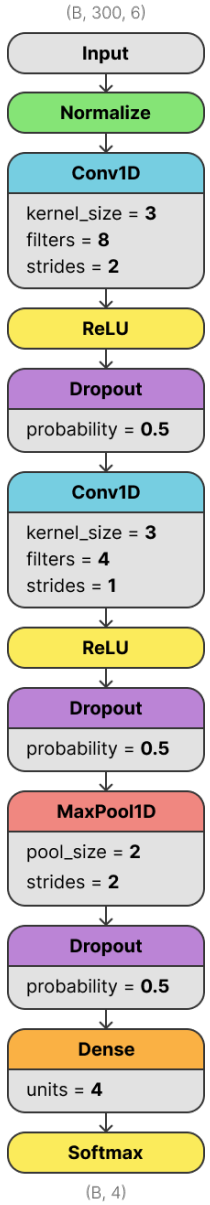
Initial Architecture

- Inspired by a network employed in Human Activity Recognition
- 38,314 weights
- 352,920 FLOPS



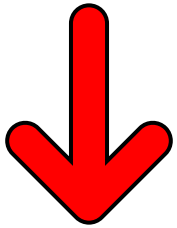
Final Architecture

- Fewer filters
- Fewer fully connected layers
- 1,456 weights
- 37,200 FLOPS



Architectures comparison

38,314 weights
352,920 FLOPS



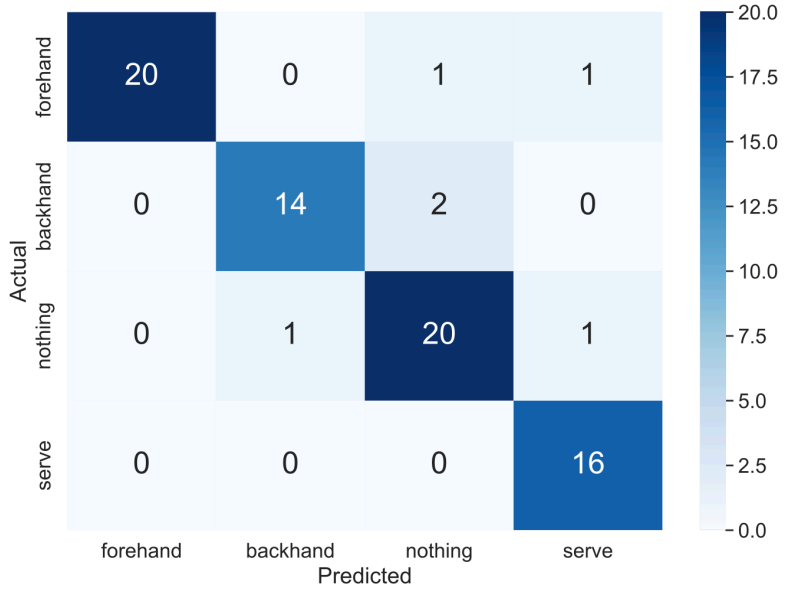
1,456 weights -96%
37,200 FLOPS -89%

Quantization

- Integer 8 bit Post Training Quantization
- First and last layer are kept FP32
- 8.6 KB final model size
- Inference time 25ms

Results

- 100% **training** accuracy
- 100% **validation** accuracy
- 99% **quantization** accuracy
- 96% **test** accuracy



- 92% **test** accuracy (*overall system*)

A Market Perspective

A Market Perspective

- Already available trackers
- Business models
  - Premium price
  - Ads on the app
  - Sell user data

An Ethic perspective

An Ethic perspective

- Pre-defined model: data remains on device
- Privacy: user data on sale

Future Developments

Improvements to the hardware, firmware and software

Future developments: firmware

- Further firmware optimization
- Battery saving mode
- Personalized user settings

Future developments: hardware

- Custom PCB
- Custom enclosure
- STM32 microcontroller: STM32-L4-96 family
- Rechargeable Li-ion battery with protection circuit

Future developments: software

- Other useful metrics
  - Swing speed
  - Ball speed
  - Shot power
  - Ball impact location
- User app
- Left-handed players

Demo