Wrist Based Sign Language Detection & Communication

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Executive Summary

Most of the public does not understand sign language, making communication difficult for those that have impaired speech and/or hearing. Existing solutions are not ideal as they require bulky, unnatural sensors or raise privacy concerns because of their need to analyze video recordings. Our solution consists of an on-wrist wearable that can translate and communicate American Sign Language in real time. The device is lightweight and energy efficient. It eliminates any privacy concerns as it does not require an internet connection and all the data remains on the device. The wearable works by acquiring rotation and acceleration data from the user's hand as they sign. This data is translated by an on-device machine-learning model into words in English. The translation is then transmitted wirelessly to a Garmin smartwatch. Finally, the translation is displayed as text by the smartwatch running our custom application, allowing people who do not understand sign language to receive the English translation directly on their smartwatch.

Overall Design

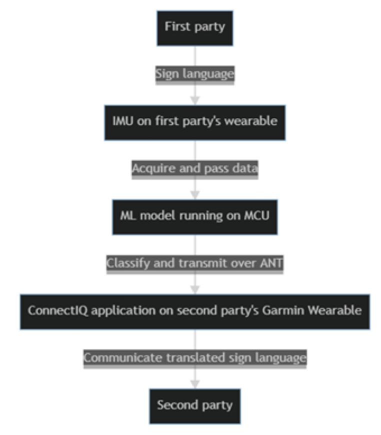

Figure 1. High-Level Block Diagram of Design

At a high level, the device worn by the user has an inertial measurement unit (IMU) and the microcontroller unit (MCU). The IMU gathers the acceleration and rotation data based on the user's hand movements. Once the data is acquired it is passed to the MCU. The tiny machine learning model performs inference on the MCU. Once the model deciphers this data and classifies the correct word, it transmits the translation using its antenna following the ANT wireless protocol. ANT defines a wireless communications protocol stack that enables communication-based in the 2.4GHz range. All of this takes place on the 'first party', who is the user signing while wearing the prototype.

The "second party" consists of the second user wearing the Garmin smartwatch that receives the transmitted translation. The Garmin smartwatch runs a custom Connect IQ application developed by our team. The application displays the translated English word to the second party.

Machine Learning Model

We trained our machine learning (ML) model using data from the IMU on the wearable. Examples of this data can be seen in Figure 2.

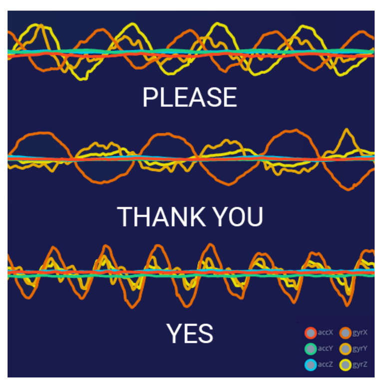

Figure 2. Example IMU data

For our ML model, we use a fully-connected 3-layer neural network. In order to fit this ML model onto our wearable and adhere to our latency requirements, we compressed our ML model from 32-bit floating point weights to 8-bit signed integers using quantization. The effects of this compression can be seen in Table 1.

Model	Flash Usage	RAM Usage	Latency	Accuracy
Quantized	172.5 kB	3.4 kB	46 ms	96.78%
Uncompressed	640.1 kB	7.2 kB	425 ms	97.82%

Table 1. The effects of quantization

Product Specifications

The following table lists the measurable technical specifications of our solution.

Category	Value
Latency	1 second
Weight (Wearable)	24 g
Weight (With straps)	64 g
Dimensions (mm)	58 x 24 x 12
Battery life	6 hours 47 min
Comfort	8.5 / 10
ML Model Size	172.5 kB
ML Model Accuracy	96.78%

Table 2. Technical Specifications

ANT Wireless Communication

The leader transmits at a frequency of 8Hz. By default, the first 6 bits of byte 0 are set to 0. When the first party starts signing, the status bit is set to 1. Once the first party has indicated that they are no longer signing, the leader sets the status bit back to 0. The follower parses bits 0 to 6 in byte 0 before proceeding to check the remainder of the data page.

An ANT data page is transmitted at every channel interval by the leader. Each character is made up of 6 bits, therefore some characters overflow between bytes and are labeled 'A' and 'B' to describe the first and second half of the character. Table 3 shows the breakdown of the first two bytes. The 6 remaining bytes follow a similar pattern. The design allows for a total of 9 characters per page.

Byte	Description	Length	Valid Range
0	Status	1 Bit (0)	0-1
0	Sequence Number	5 Bits (1:5)	0-31
0	Character One A	2 Bits (6:7)	0-25
1	Character One B	4 Bits (0:3)	0-25
1	Character Two A	4 Bits (4:7)	0-25

Table 3. ANT Data Page (bytes 0-1)

Connect IQ Application

Figure 3 illustrates the flow of the Connect IQ application with respect to the incoming ANT messages. The Connect IQ application is a stateful application that is dependent on the contents of the incoming ANT messages. The application parses the status, sequence number, overflow, and payload (i.e., the rest of the data page) in that order and shifts states depending on the outcome of each parsing step – this is visualized in this state diagram.

Figure 3. State Diagram of Connect IQ APP

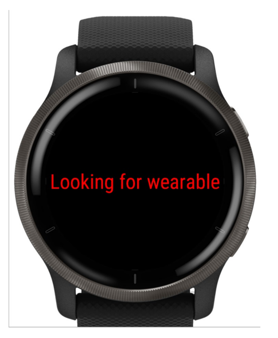

Figure 4. Searching

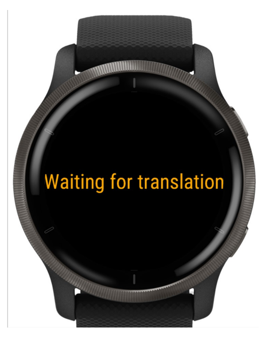

Figure 5. Waiting

Figure 6. Translating "Please"

Physical Components

Board

The board is powered using a 3.7V 110mAH Lithium-Ion Polymer battery. The IMU used is a 9-axis IMU, the LSM9DS1. It measures linear acceleration, magnetic field, and angular rate – for our application, we will only use the accelerometer and gyroscope. Our board uses the NINA-B306 module which contains the nRF52840 MCU and an embedded 2.4GHz antenna that will be used for the ANT wireless communication. When the board is supplied 3.3V, each component will draw a specific amount of current, summarized in the power tree below.

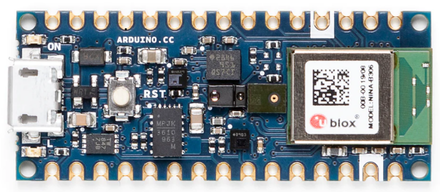

Figure 7. Board [1]

Enclosure

The enclosure is 3D printed of PLA plastic. During the design process, this allowed for quick and fast iteration. The enclosure is large enough to support the PCB, battery, and required fasteners.

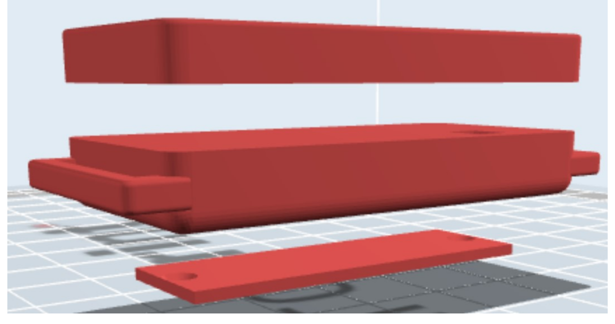

Figure 8. 3D-Render of Enclosure

References

[1] Arduino nano 33 BLE sense. *https://store-usa.arduino.cc/products/arduino-nano-33-ble-sense*, 2023.

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