Designing a Software Receiver for Gesture Recognition with Ambient Light

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1. Background

There is a growing need for touch-free interaction with public utilities such as coffeemakers and vending machines that will help prevent the spread of diseases such as COVID-19. One solution is the adoption of embedded gesture recognition systems relying on ambient light. However, existing work so far is found to be inefficient, either requiring too costly and large-scale hardware [1, 2] or supporting only a small number of gestures unsuitable for practical applications [3].

Photodiode Sensor	Visible Ambient Light
- Outputs a signal proportional to the amount of incident light.	- Light in the visible spectrum that is not set up or controlled.
- Sensitivity can be adjusted using a resistor feedback loop.	- Examples: Sunlight and room illumination.

2. Research Question

This research designs and implements a software-based receiver pipeline that collects real-time gesture data and processes it for classification by a Machine Learning (ML) model. It is part of the development of a small-scale gesture recognition system using ambient light (see Figure 1) and answers the following question:

How to design a receiver to detect visible light signals with one Arduino Nano 33 BLE and 3 OPT101 photodiodes, and how to proceed the signals efficiently?

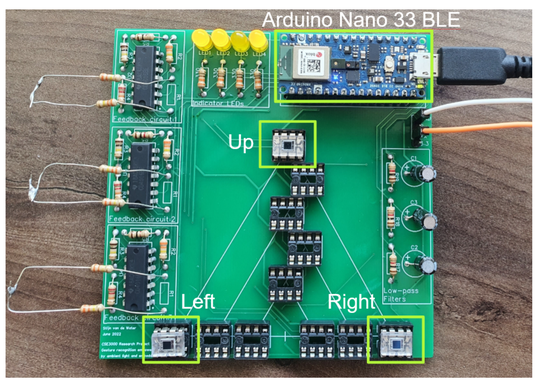

Figure 1: Gesture Recognition Prototype: 3 photodiodes and Arduino

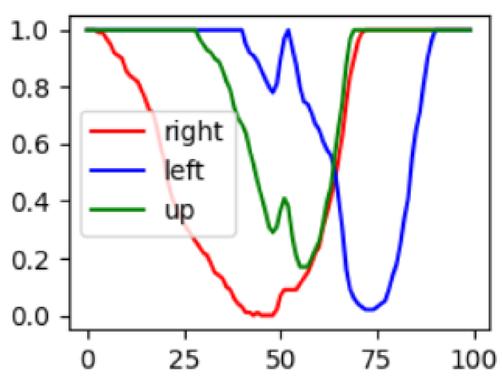

Figure 2: Sudden light intensity increase during a gesture

3. Challenges

1. Gesture data varies in length due to different user hand motion speeds.
2. Static ambient light intensity in the environment can change, affecting the dynamic range of the data.
3. Gesture data can be noisy because of moving objects in the background.
4. The receiver pipeline has to support real-time processing.

4. Receiver Design

1. Photodiode sampling frequency of 100 Hz.
2. Gesture detection: multiple samples are below/above a threshold.
3. Noise reduction: use FFT to remove frequencies above 5 Hz.
4. Normalisation: Map each signal to the range $[0, 1]$ using its minimum.
5. Stretch each signal's data using linear interpolation to a fixed length.

5. Evaluation Results

+ Significant suppression of fluctuations in the photodiodes' data.
+ Condition-independent output format with equal scaling in both axes.
+ Preprocessing is done in around 20 ms.
- No support for light changes during a gesture (see Figure 2).
- FFT can introduce fluctuations in flatter signal regions.

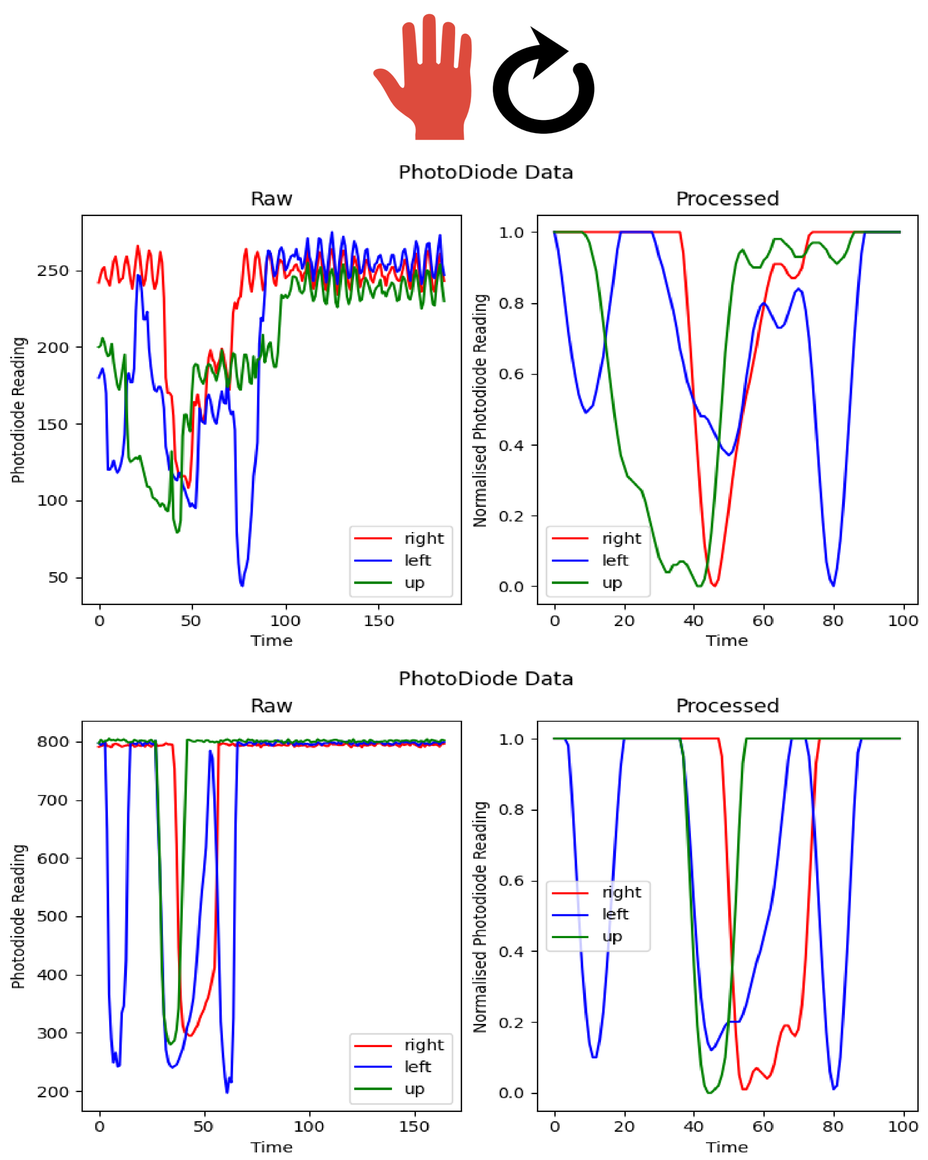

Figure 3: Clockwise Hand Rotation signal passed through the receiver pipeline in 100 Lux (top) and 700 Lux (bottom). On the left the signal is in the range $(0, threshold)$. On the right the signal is in the range $(0, 1)$.

6. Future Work

1. Code optimisation: switch from FFT filtering to convolution with a low-pass filter - expected polynomially smaller time complexity but requires dynamic coefficient adjustment.
2. Pipeline extension: support for additional environment dynamics like light changes in the middle of a gesture.

References

[1] M.-D. A. Kaholokula, "Reusing ambient light to recognize hand gestures," 2016, *Dartmouth College Undergraduate Theses*, 105.

[2] D. Ma, G. Lan, M. Hassan, W. Hu, M. B. Upama, A. Uddin, and M. Youssef, "Solargest: Ubiquitous and battery-free gesture recognition using solar cells," *CoRR*, vol. abs/1812.01766, 2018. [Online]. Available: http://arxiv.org/abs/1812.01766

[3] G. V, S. Salvi, P. Sahoo, M. Dodiya, and S. Gupta, "A shadow based low-cost hand movement recognition system for human computer interaction," in *International Conference for Convergence in Technology (I2CT)*, 2021, pp. 1–4.