Designing an adaptable and low-cost system for gesture recognition using visible light

CSE3000 Research Project
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1 Background

- Existing gesture recognition systems often use a sensing medium, such as infrared light, that is controlled by the system itself
- Gesture recognition with ambient light has some key advantages:
  - Lower power consumption
  - Lower cost
  - More space efficient

- Gesture recognition with ambient light also has disadvantages:
  - Unclear how data should be interpreted
  - Unclear how sensing is affected in changing environments

2 System Overview

- Hardware components for the gesture recognition system:
  - 1 Arduino Nano 33 BLE microcontroller
  - 3 OPT101 photodiodes
  - 3 CD4016BE
  - A range of passive components (resistors, capacitors)

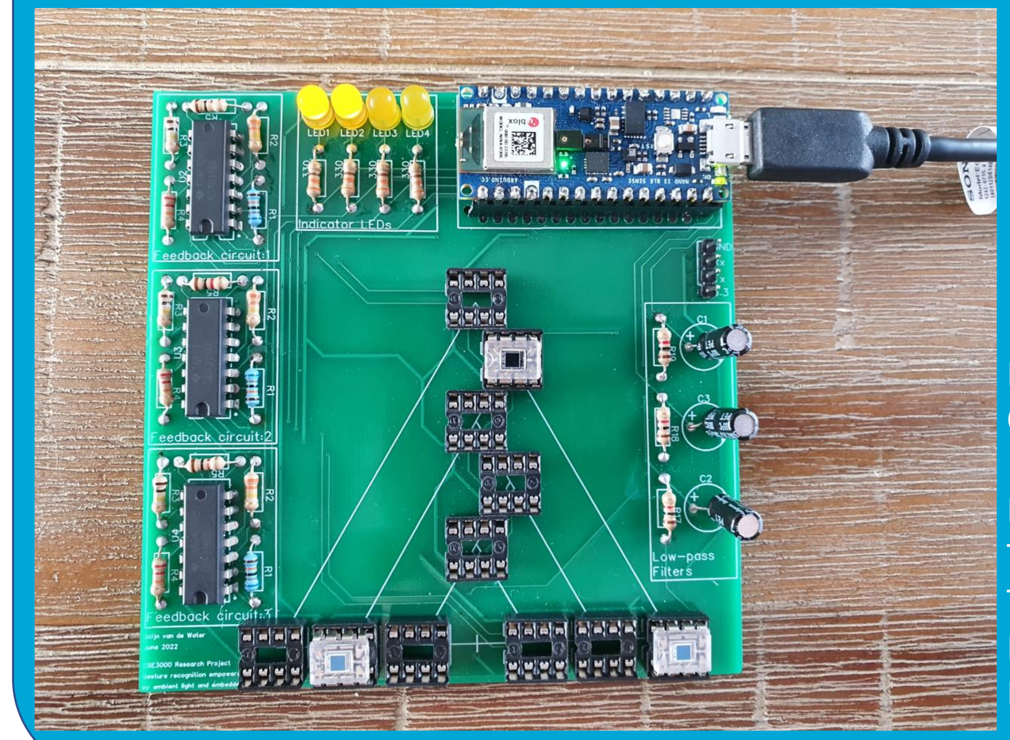

Figure 1.
Overview of the system.

Left: Digital potentiometer
Top middle: Indicator LEDs
Top right: Arduino Nano 33 BLE
Right: RC low-pass filters
Middle: OPT101 triangles

3 Research Question

How to optimize the sensing performance of the OPT101 photodiodes?

The main question can be split up into 2 sub-questions:

1. What is the impact of ambient light on the sensing performance?
2. What is the impact of the placement of photodiodes on the sensing performance?

4 What is the impact of ambient light on the sensing performance?

Impact of ambient light level

- The OPT101 photodiode outputs voltage according to the following formula: $Vout = Id * Rf + Vb$. [1]
- Output voltage can thus be adjusted by the resistive value of the feedback circuit (Rf). (Figure 2)
- By employing a digital potentiometer, the system can adaptively change Rf, effectively broadening the effective sensing range

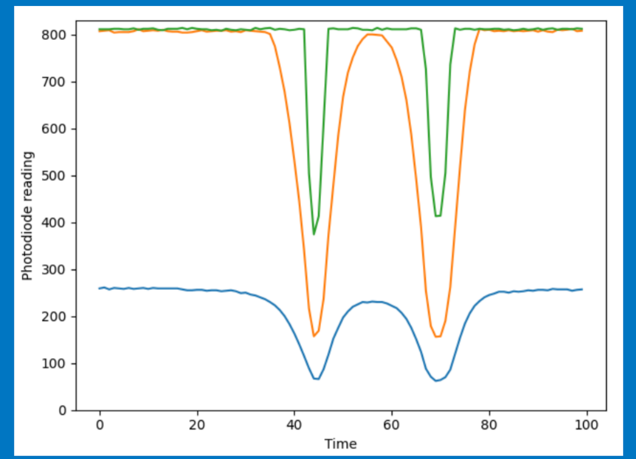

Figure 2. Demonstrating the effect of the feedback resistor (Rf) on photodiode reading
Green: 1MΩ, Orange: 330kΩ, Blue 100kΩ

Environmental Noise

- 50Hz AC in artificial lights leads to noise in received lighting. [2] The full signal can be reconstructed by measuring at 100Hz. Subsequent data processing can then reduce the noise.

- High frequency noise when the photodiodes are subjected to full sunlight. (Figure 3a). By including a 1kΩ, 10µF RC low-pass filter this noise is entirely removed. (Figure 3b)

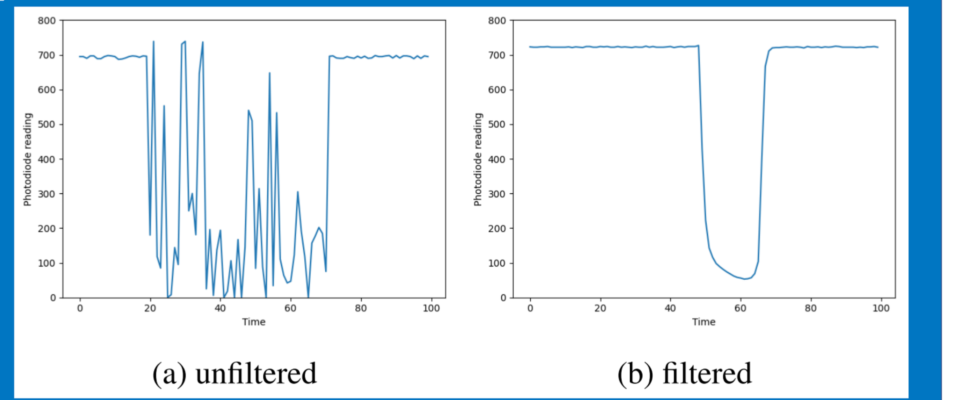

Figure 3. Effect of RC low-pass filter at 150.000 Lux

Results

- Figure 4 shows the optimal resistor at each light intensity level
- With 22 kΩ, 100 kΩ, 330 kΩ, and 680 kΩ, it is possible to achieve excellent sensing from 50 – 150.000 Lux. (Figure 5)

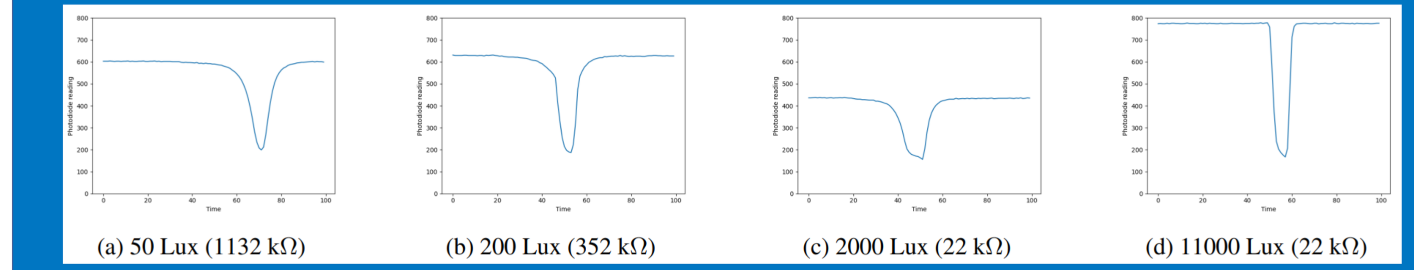

Figure 5. Tap gesture performed at different light intensities.

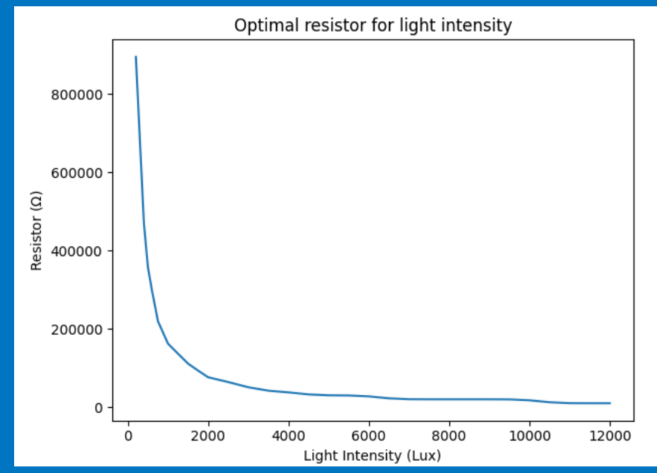

Figure 4. Plot showing optimal resistor values for different light intensities

5 What is the impact of the placement on the sensing performance?

Placement pattern of photodiodes

- **Distance between photodiodes**
  - Too small -> Unable to capture gesture due to limited time delay.
  - Too large -> Unable to fully capture gesture.
  - Distances from 2cm to 6cm are considered.
- **Angle between photodiodes**
  - Can be used to increase performance of specific gestures. For example angles of (0, 180, 0) will form a straight line and is excellent for detecting Left/Right hand gestures.
  - Multiple different angles will be considered starting from an equilateral triangle (60, 60, 60) to (80, 20, 80) and (25, 130, 25)

Photodiode configuration scoring

- Gestures considered for selection of optimal placement: Swipe Left, Swipe Right, Swipe Up, Swipe Down, and Tap.
- A total of 1800 samples are used for scoring.

- Each photodiode configuration will be scored using a Dynamic Time Warping (DTW) algorithm. DTW first optimally aligns two gestures by stretching/compressing time non-linearly, and then calculates the Euclidean distance.
- Distance for all possible matchups are calculated resulting in a distances matrix.

- The distance matrix is processed using two methods: Normalization and Subtraction.
- Finally all elements of the processed matrices are summed up, resulting in the final scores.

Results

- Figure 5 shows the final scores for each photodiode configurations.
- It is evident that both increasing the width and height of the triangle has an positive effect on the performance of the system.

- The best performing photodiode configuration is 666_606060, however distances of 6cm are too wide, causing gestures to be only sensed partially. (This is effectively dealt with by DTW, so the effect is not visible)

Configuration	Normalized Score	Subtracted Score
666_606060	68.1	150.6
555_606060	64.6	117.8
444_606060	55.5	85.1
333_606060	55.9	62.0
222_606060	44.5	33.2
424_753075	52.2	56.5
626_802080	50.2	79.2
343_4010040	56.3	68.1
464_2513025	61.6	100.1

Figure 5. Final photodiode configuration scores

- At distances of 5cm the impact of this issue is greatly reduced.

- Therefore the photodiode configuration 555_606060 is the best placement.

	left	right	up	down	tap
left	2.08	12.52	8.73	9.39	7.70
right	12.52	2.77	9.52	9.89	8.23
up	8.73	9.52	3.93	11.69	7.42
down	9.39	9.89	11.69	3.80	7.95
tap	7.70	8.23	7.42	7.95	4.48

Original

	left	right	up	down	tap
left	1.00	4.51	2.22	2.47	1.72
right	6.01	1.00	2.42	2.60	1.84
up	4.19	3.43	1.00	3.08	1.66
down	4.51	3.57	2.97	1.00	1.78
tap	3.70	2.97	1.89	2.09	1.00

Column normalized

	left	right	up	down	tap
left	0.00	9.75	4.80	5.59	3.22
right	10.44	0.00	5.59	6.09	3.76
up	6.64	6.75	0.00	7.89	2.94
down	7.31	7.12	7.76	0.00	3.47
tap	5.62	5.46	3.49	4.15	0.00

Column subtracted

Figure 6. Scores for the 555_606060 photodiode configuration

6 Conclusion

- Through the utilization of a custom digital potentiometer, effective sensing can be achieved in environments from 50 – 150.000 Lux.
- Noise from light sources is greatly reduced, improving the sensing performance of the system.
- The optimal placement is a equilateral triangle with sides of 5cm, which allows for the optimal extraction of data.

7 References

[1] Texas Instruments. Opt101 monolithic photodiode and single-supply transimpedance amplifier, January 1994 revised June 2015.
[2] Dong Ma, Guohao Lan, Mahbub Hassan, Wen Hu, Mushfika B Upama, Ashraf Uddin, and Moustafa Youssef. Solargest: Ubiquitous and battery-free gesture recognition using solar cells. In The 25th Annual International Conference on Mobile Computing and Networking, pages 1–15, 2019.

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