Measuring muscle movements with reflective photosensors

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Measuring muscle movements with reflective photosensors

Mätning av muskelrörelse med reflekterande fotosensorer

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Abstract

Optomyography is the term chosen to name a device containing several reflective photosensors placed in an armband. The device is constructed so that it can measure muscle movements in the arm through the detection of skin structure variation. The aims of this research were to build such a device that is capable of expressing the structure changes in form of intensity changes in light emitting diodes and determine whether it is possible to distinguish different muscle movements. This was accomplished by designing and testing two different circuit schematics for Optomyography that differ depending on whether the outgoing signal is processed or not. The schematics were then used to build two electrical circuits of Optomyography that were tested with several subjects to see if they were functioning. The results show that only the version of Optomyography, which processes the outgoing signal with a high-pass filter and amplifies it, is able to detect muscle movements through skin structure variations. However, further investigation of the device is needed to see if different movements can be distinguished.

Keywords: Optomyography, muscle movements, skin surface variation, reflective photosensor.
Sammanfattning


Nyckelord: Optomyografi, muskelrörelse, variation i hudsstrukturen, reflektiv fotosensor.
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1. Introduction

Optomyography (OMG) is the name that was chosen for a device that measures muscle movements through skin variation with the use of multiple reflective photosensors. The term, Optomyography, is of Latin origin meaning muscle measuring (-myography) with the use of light (opto-).

The goal of this project is to test the possibility of measuring hand and finger muscle movements through skin variations by using reflective photosensors according to two different circuit schematics versions. The purpose of the different schematics is to try to determine whether a high-pass filter and amplifier is needed to measure the differences.

This is done by designing and constructing an Optomyography armband and testing its capability to detect reflected light from different skin structure changes. The measured changes occur on the skin surface of the arm and about 1 mm under the skin as finger and hand movements are performed. The changes will be presented by intensity differences in LED lamps.

The purpose is to develop an alternative non-invasive method to measure muscle movements than Electromyography (EMG) and thus be used in medical facilities to measure the muscle movements of patients. There are several other disadvantages to Electromyography that are presented in the Background section.

Furthermore, there are several future appliances for Optomyography, such as the possibility of using Optomyography for helping patients with a prosthetic glove or hand by knowing what type of control signal is needed to be generated for optimizing and strengthen the movements that the patient is trying to perform (Wolf et al., 2012).

Another one is for surgery purposes. A surgeon can use Optomyography to control an artificial arm that can be used for more precise operations or skilled surgeons can use it to operate on patients in different countries (Wolf et al., 2012).

The number of possible appliances of a functioning Optomyography is numerous as it can be used to control several types of devices with hand gestures, such as drones (Zeitnews, 2014).
2. Background

In this subsection, some important concepts for building Optomyography are explained. Furthermore, a few relevant studies of muscle movements and blood flow with reflected photosensors are presented and also Electromyography, a relevant muscle movement detection method, is explained.

2.1 Placing of the Armband

There are several muscles located between the wrist and elbow on the posterior and anterior side of the arm. As each finger or the entire hand is moved, the change in the arm will be greatest there. The Optomyography armband was placed on the arm below the elbow (Taylor, 2013).

2.2 Reflective Photosensors

Reflective photosensors are electrical components that consist of a diode and a phototransistor. The diode emits infrared light and the phototransistor detects the reflected light with a high sensitivity (IHS GlobalSpec, 2014).

In this research, the RPR-220 reflective phototransistor was used in constructing Optomyography. According to its datasheet, the emitter in this case is a diode made of Gallium Arsenide (GaAs) and the detector is a silicon planar reflector (ROHM, 2014a).

2.3 Operational Amplifier

Operational amplifiers are electrical components consisting of transistors, capacitors and resistors. Operational amplifiers are usually referred as opamp; their main purpose is to amplify an input signal to the output signal, but can also work as switches. Opamp is a differential amplifier in the sense that it consists of two input terminals, one positive respectively one negative; the difference between these terminals is what determines the output voltage. The differential amplifier is connected with two external sources that work as an overvoltage, which limits the amplification in voltage to the external source connected (Spencer, 2009).

The opamp INA126 was used in building the second version of Optomyography. It is an instrumental amplifier consisting of two smaller amplifiers. It has an amplification factor $G = 5 + \frac{80k\Omega}{R_G}$, where $R_G$ is the gain resistor. The G-factor determines how many times the input signal is enlarged and generated as an output signal, see figure 1 (Mirdha, 2014c).
2.4 High-Pass Filter
A high-pass filter is an electronic filter consisting of a capacitor in series with the \( V_{in} \) signal and a resistor that is connected to ground, see figure 2 (Stark, 2004).

Stark (2004) states that the main purpose of high-pass filters is to only allow high frequency signals to pass through. When low-frequency signals reach the capacitor, the circuit turns into an open circuit and thus it filters out the low-frequency signals (Stark, 2004).

2.5 Electromyography
Merletti and Parker (2004) define electromyography (EMG) as the study of muscle stimulations through contraction and extension. A resting muscle does not generate any measurable signal but if the muscle contracts or extends, it generates a detectable signal that is shaped as a continuous wave (Merletti and Parker, 2004).

When nerves are stimulated, during a muscle contraction, the cells create a visible electrical signal on an oscilloscope. This is due to the fact that muscle fibers produce action potentials and EMG can detect these signals with electrodes that penetrate the skin of the patient (Johns Hopkins Medicine Health Library, 2014).

The main disadvantages of electromyography are that it is an invasive method and also a bit painful. Furthermore, it can be effected by nearby electrical signals and thus decrease the signal-to-noise ratio (McDonough, 2014).

2.6 Project: an IR Muscle Contraction Sensor
Subramaniam (2013) built a device for measuring muscle contractions using reflective photosensors that mainly measured bicep and also the force of contraction. The main purpose of the project was to create a substitute non-invasive method to measure biceps movements to electromyography (Subramaniam, 2013).

The circuit schematics for the project includes, besides the sensor, a high-pass filter, an operational amplifier and a band-pass filter (Subramaniam, 2013).

2.7 Project: Move Your Music
Barnett and Galanko (2012) have constructed a method regarding controlling music apparatus with hand gestures. This is done by photo sensors, similar to the ones used in this project, placed on the arm with the help of an armband. With an AC/DC converter they were able to interpret the phototransistor signals into digital waveforms. Using an implemented MATLAB code, frequency changes to different songs depending on the arm movement were made detectable (Barnett and Galanko, 2012).

The schematics for the photo sensor consisted of a high-pass filter, low-pass filter and a differential amplifier (Barnett and Galanko, 2012).
2.8 Measuring Blood Flow with Photosensors

Mirdha (2014) states that measuring blood flow by using reflective photosensors is possible. The basic principle is that the photosensor is placed on the surface of the area desired to be measured. The photosensor’s diode then emits an infrared ray into the blood flow and its transistor collects the reflected ray, which it forms into an electrical signal (Mirdha, 2014a).

Mirdha (2014) explains that due to the weak electrical signals that are received from the measurement, both a high-pass filter and an amplifier is needed to measure the blood flow. A low-pass filter is then used to increase the signal to noise ratio (Mirdha, 2014b).

2.9 Optomyogram

Fisher, Singh and Gupta (2013) from Cornell University built a similar device as Optomyography to measure finger movements with the help of photosensors, which was built by using one infrared emitter and four phototransistors. The gathered data from the experiment was later processed with a MATLAB code to detect which finger had moved. The project used a circuit schematic consisting of the sensor, a high-pass filter, level shifter and a band-pass amplifier. The project was successful in only detecting three fingers (Fisher et al., 2013).

The Optomyography project was conducted without the knowledge of the Optomyogram report’s existence. Therefore, Optomyography was constructed independent from their project.
3. Method and Implementation

3.1 Bill of Materials

The materials required to build the Optomyography were:

- Twenty RPR-220 reflective photosensors.
- 10Ω, 120Ω, 1.8KΩ and 10MΩ Resistors with 0.25W effect.
- 6.8µF Capacitor
- INA 126P operational amplifier
- 10 white LED lamps (264-15/T2C4-1NRB) with 3mm diameter.
- Epoxy photoresist printed circuit board (PCB).
- Breadboard.
- Forty one-meter-long wires.
- Styrofoam box.
- Two mobile cameras.
- Electrical tape.
- Super glue.
- Black heat-shrink tubing.
- Apple Mobil Charger with 5 Volt and 1 Ampere.
- A circular holder constructed from a Faber-Castell green overhead marker with a fine tip.
- Overhead paper

Furthermore, equipment such as a multimeter, a function generator and an oscilloscope, were used to test the components. The tests were usually done to measure the resistance of the resistors, the voltage over and the current through several junctions in the circuit. The function generator was primarily used to test the INA126 amplifier.

Moreover, the following tools were used:

- CadSoft EAGLE was used to digitally design the circuit schematics.
- Denatured alcohol, sodium hydroxide and etching bath chemical mix were used to etch the circuit board.
- Soldering iron, solder and desoldering pump were used to solder the components on the circuit board.
- Silicone gun was used to darken the Styrofoam box with a layer of ultra-thin black foam.

Lastly, Optomyography was tested on three persons. Test subject A and C were male while test subject B was female. All subjects were 21 years old with no known medical conditions regarding the bones’ or muscles’ function on the tested arm.

3.2 Method

The process of building the Optomyography is divided into mainly three parts:

- Designing the circuit schematics.
- Assembling the components.
- Gathering and analysing the measured data.
3.2.1 Designing the Circuit Schematics

The main requirement for the device was that a mobile charger with a power source of 5 volts and 1 Ampere should be enough to power all the components. To accomplish that an Apple mobile charger was modified by cutting the cable and soldering the ends, so that it could be attached to the circuit as a power supplier. Moreover, two different functioning circuit schematics were designed to fulfill the previous requirement.

**First Circuit Schematic:**

The first circuit schematic was divided into two parts for each reflective photosensor; the main component of each part consists of the diode (Part A) or the phototransistor (Part B).

Part A’s main goal is to power the diode with right amount of voltage. According to the data sheet of the RPR-220 photosensor, the diode produces the max amount of light rays when it is applied with 1.5 volts (ROHM, 2014b). In order to achieve this, the diode had to be connected in series with two 10Ω resistors.

Part B consists of the phototransistor, which also needed to be connected to a power source in order to gather the reflected rays and produce a signal that can be used to power the LED lamps (ROHM, 2014b). The signal is then directly connected in series to a LED lamp.

Ten reflective photosensors were lastly parallel connected to the power source and built the first version of Optomyography.

The software CadSoft EAGLE was used to design the circuit schematic for the etching part by following Malmqvist’s instructions (Malmqvist, 2013).

**Second Circuit Schematic:**

The second schematic was also divided into two parts. The first one, Part A, was designed exactly the same as the one in the first circuit schematic. The difference between both schematics lies in how Part B is designed. The signal from the phototransistor in the second schematics is processed by a signal processing circuit before being connected to a LED lamp.

The signal processing circuit consists of a 1.8KΩ and 120Ω resistors that are then connected in series to a high-pass filter (consisting of the capacitor and a 1MΩ resistor) and an amplifying circuit.

The configuring of the amplifying circuit (the opamp INA126) was done accordingly to Texas Instruments’ datasheet and it consisted of an INA 126 operational amplifier, a 10Ω resistor and two inputs of 12V and -12V. It was connected according to the schematics in figure 2 in the previous section (Texas Instruments, 2014)

In the second schematics only one reflective photosensor with a signal processing circuit was used to build Optomyography. The sensor was placed in a green cylindrical holder, see figure 10 in appendix B.
3.2.2 Assembling the components

The microfabrication was only used to build a circuit board to the first schematics and it was accomplished by chemical etching in the Mechatronic division at the Royal Institute of Technology (KTH). All the tools required for manufacturing the circuit board, i.e. drill, was available there.

The circuit schematic was printed out from software EAGLE onto an overhead paper, which was then placed in front of a copper-based plate that was bought from Elfa Distrelec. The plate was then exposed to ultraviolet light and later put into two different chemical bowls. The first bowl contained sodium hydroxide (NaOH) and was used to develop the schematics on the board. The second bowl was the etching bath and it removed the copper from the unwanted areas. Until the board was placed in the etching bath, the board was prevented of being exposed to any light (Kjell & Company, 2014).

Consequently only the copper, which was covered by the schematic drawing, was left on the plate. The copper was then washed by denatured alcohol to increase the copper’s ability to solder components on it (Kjell & Company, 2014).

After the completion of the board, all components (LED, resistors and the wires) were soldered on to the board according to the schematic at Campus Flemingsberg. Heat-shrink tubing for isolation was also used to cover the wires’ ends.

The final part was to glue the photosensors to the Optomyography armband and soldering them to the board with the wires. Subsequently the Styrofoam box, which was constructed with help from Svensk Emballage Teknik AB in their factory, was blackened with the black foam to minimize room light interference.

The second version of Optomyography was constructed on a breadboard instead at Campus Flemingsberg. All components were placed on the breadboard according to its schematics. The data was collected outside of the box.

3.2.3 Gathering and analysing the measured data

Testing of the first version was done with two cameras, one to record hand and arm movement of test subjects A, B and C while the other to record the LED lamps intensity changes. The test subjects were instructed to move the hand and fingers, accordingly to pre-established procedures that were presented in the report: Decoding Static and Dynamic Arm and Hand Gestures from the JPL BioSleeve (Wolf et al., 2012).

The second version, however, was only tested on test subject A. Furthermore only one camera was used to capture both the movements of test subject A and the intensity differences of the LED lamp.

The captured videos were supposed to be analyzed by a MATLAB code to see if there occurs any differences in the intensity of the LED lamps. Moreover, it was to be used to see if different hand and finger movements could be distinguished.
4. Results

The building of the first version of Optomyography on the circuit board and soldering the components on it was completed and so was the building of the armband and connecting it to the circuit board. Furthermore, blackening the measuring box was also done; see the figures in appendix A.

The first version of Optomyography did show significant changes in intensity when the distance change was more than one centimeter. After studying the captured videos of the first version of Optomyography, the subjecting the videos to the MATLAB code was considered to be useless.

The building of the second version on the breadboard was also completed; see the figures in appendix B. However, the second version of Optomyography did show difference from a distance of 5 mm from the skin.

Furthermore, due to time shortage, the second version could not also be subjected to the eventual MATLAB code.

The circuit schematic of the first version is presented in figure 3 and the schematic of the second is presented in figure 4.

Figure 3: One photosensor circuit, version 1.

Figure 4: One photosensor circuit, version 2.
4.1 First version
Testing of the first version of Optomyography with test subject A and B gave negative result with eye observation; see table 1 below and video 1 in appendix A.

During the recording of test subject C, the LED lamp, placed on the outermost left, gave a steady blinking as the wire connected to the transistor was displaced during different hand and arm movements from test subject C. The other nine LED lamps gave a negative result with eye observation, meaning that no intensity differences were spotted; see table 1 below and video 2 in appendix A.

The design of the first schematics made the voltage across the phototransistors change from approximately 5 volts to 0.2 volts when the transistors were placed on the skin. This made the sensor not able to detect difference when the object moved from a distance smaller than one centimeter.

4.2 Second Version
The second version of Optomyography was only tested with test subject A. The LED lamp did not change its intensity the first few seconds, but then it did show a significant change in intensity as different hand and finger movements were performed; see table 1 below and video 3 in appendix B. The design of the second schematics made the drop from 5 volts to 2.5 volts when the transistors were placed on the skin.

The signal processing circuit removed all the low-frequency signals and thus made sure that only the desired signals produced from different movements (high frequency signals) were left. The amplifying circuit then increased with a gain factor of 8000 times according to the gain equation presented in section 1.1.3.

<table>
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<th>Test Subject</th>
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<th>Recorded</th>
<th>Intensity Changes</th>
<th>Comments</th>
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<tbody>
<tr>
<td></td>
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<td>Version 2</td>
<td>Version 1</td>
<td>Version 2</td>
</tr>
<tr>
<td>A</td>
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<td>Yes</td>
<td>No*</td>
<td>Yes</td>
</tr>
<tr>
<td>B</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No**</td>
</tr>
</tbody>
</table>

*Only eye observation.

Table 1: Results from test subject A, B and C.
5. Discussion
The first version of Optomyography could not be used to measure skin structure differences during arm and hand movements because primary of the great voltage drop. However, the second version was more successful and showed significant intensity differences. Nevertheless, the method needs to be tested further with more photosensors and more test persons.

5.1 Optomyography: First Version
There were two 10Ω (R₁ and R₂ in figure 3, page 9) instead of one 20Ω resistor due to the fact that the effect would be too high on one resistor. The resistor would most probably burn because too much heat would be produced. There were no significant changes whether one or two resistors were used.

When subject C was tested with Optomyography, the reason that diode on the furthest left blinked steadily was because the wire connected to the diode moved with the hand movements. This occurred because the wire had half-loosened from the circuit board and turned the power on and off when it moved during hand and finger movements.

Unlike subject A, subjects B and C were instructed to repeat each hand or finger movement three times and always return to a self-chosen initial position. By doing this, the results for every movement would have been easier verified if the first version had worked. Moreover, any occurring errors would have been identified by cross checking all movements with their results.

After studying the videos of test subjects, a conclusion was drawn that the MATLAB code to study the light intensity was unnecessary to use. The reason behind the conclusion was that there were no visible changes and the code would have one giving us a negative value.

5.2 Optomyography: Second Version
The reason why the voltage drop in the second schematics was 2.5 volts was due to the resistance placed parallel to the signal (R₃ and R₄ in figure 4, page 9). After the high-pass filter, the remaining high-frequency signal was too small to power a LED lamp and that is why it was necessary to use the instrumental amplifier, INA126P.

In the second version, the photosensor produced better signals when it was approximately 0.5cm apart from the skin, due to better skin penetration of the infrared light produced by the diode in the photosensor. Therefore, the cylindrical holder was placed around the sensor. Even when the same object was placed around a sensor in the first version Optomyography, it did not produce a measurable signal.

The reason why in first few seconds when the sensor was placed on the skin, it could not detect any differences was because the capacitor in the high-pass filter was charging. After the charging phase, the differences could be measured.
The testing of the second version was not enough to establish that it could distinguish different finger and hand movements but only that we could see a difference. Further measuring with several sensors is needed.

### 5.3 Limitations

The main limitation was that the timespan was not enough to thoroughly study and investigate the signal changes in finger and hand movements through several tests on the oscilloscope. Furthermore, this study was limited to the usage of type RPR-220 photosensors from ROHM and that the signal variation must be displayed by LED lamps.

### 5.4 Errors

The human factor of measuring the intensity difference with the eye might be included to the list of possible errors. There might have been a very small difference in the diode intensity, but it is not probable.

Besides the human error factor, the photosensors in the armband of the first version of Optomyography were not stable and it was necessary to make sure that the sensors were placed vertically on the skin before every measurements. However, the sensors might have been angled a few degrees short from the vertical angle. In the second version, the sensor was held by hand vertically on the skin. Therefore, it might have been unstable during the measuring.

### 5.5 Optomyogram

Both versions of Optomyography were constructed without the prior knowledge of Fisher, Singh and Gupta’s work in Optomyogram (Fisher et al., 2013). The main difference between Optomyography and Optomyogram is that the transistor in the photosensor used in Optomyogram detected light that was penetrated through the entire arm. However, in Optomyography the detected light was reflected from the skin.

Until the second version of Optomyography has been further tested, concluding which device is better is virtually impossible. However, Optomyography might have a huge advantage over Optomyogram due to the fact that it measures reflected rays. Meaning that it would need less ray energy and the same device would work on all sorts of people regardless of skin color.

### 5.6 Future applications

As mentioned before in the introduction, there are several future appliances for Optomyography and several advantages for the continued research into the subject of measuring muscle movements with reflective photosensors.

In comparison with Electromyography, a device constructed of reflective photosensors is a lot cheaper and more comfortable for the patient. Furthermore, it isn’t affected by nearby electrical signals and thus increases the signal-to noise ratio. It is also more suitable for hemophilic patients and needle-scared children, as well as adults.
If Optomyography were that precise that it could be used to operate a drone arm by a surgeon to preformed an operation in a different country, the technology would be able to save countless lives all over the world. Furthermore, these drone arms could be used in hostile areas, such as in conflict zones, without endangering the medical personal.

5.7 Improvements
The most significant improvement that can be made is to convert the data with an AC/DC-converter to an implemented code, such as MATLAB. This will allow a better monitoring of the signals and how components values can be changed to improve it, i.e. higher gain factor. Furthermore, this would also be a significant factor in determining whether the data could be used to distinguish different movements of the fingers or the hand by checking and cross checking the received signals from different movements.

As suggested before, the second version of Optomyography should include several more photosensors and should be placed on a hardened object to make sure they are positioned vertically on the skin’s surface with an approximate distance of 0.5 cm.

If the possibility of redoing this project existed the biggest changes would be altered in the construction of the armband. The armband would instead be made of ten plastic rectangles that hold the photosensor steady and between each rectangular would be an elastic band, so that the armband itself could expand to suit the test subject’s arm. Moreover, the distance between each diode would be increased, so that the recording would be a lot easier.
6. Conclusion

This study has concluded that measuring significant changes on the skin surface during hand and finger movements with photosensors is possible. Therefore, photosensors can be used to measure muscles during arm and finger movements. However, it is necessary to use circuit schematics similar to the second version of Optomyography that is presented in this paper, which includes a high-pass filter and an amplifier.

Consequently, it can also be concluded that photosensors could be used in the future to replace the invasive method of electromyography.
7. Acknowledgment

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Appendix A

Figure A-1: Optomyography circuit, version 1.

Figure A-2: the circuit board with all components, version 1.
Figure A-3: The circuit board of Optomyography, version 1.

Video 1 of test subject B: [http://youtu.be/m530SyclON4](http://youtu.be/m530SyclON4)

Video 2 of test subject C: [http://youtu.be/16FVWAaO3nc](http://youtu.be/16FVWAaO3nc)

Figure A-4: The entire set up, version 1.
Appendix B

Figure B-1: The breadboard connections in the second version of Optomyography.

Figure B-2: A photosensor placed in a cylindrical holder.

Video 3 of test subject A: http://youtu.be/v348IfpH2Aw