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NONINTRUSIVE HEART RATE MONITORING: A COMPARATIVE CASE STUDY OF LED OPTICAL SENSOR'S ACCURACY

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Abstract

In recent years many researchers are focusing on non-intrusive measuring methods when it comes to human biosignals. These methods provide solutions for everyday use, whether it's health monitoring or finessing the workout routine. One of the biggest issues with these solutions is that the sensors' accuracy is highly variable due to many factors, such as ambiental light, skin color diversity, etc. That is why we wanted to explore different outcomes under those kinds of circumstances, in order to find the most optimal algorithm for extracting heart rate information. The optimization of such algorithms can benefit the wider, cheaper and safer application of home health monitoring, without having to visit medical professionals as often when it comes to observing heart irregularities. The accuracy of a LED optical sensor was explored in a controlled environment and the results were compared with a medically accurate heart rate monitoring device. This case study provides a comparison of heart rate measurements from the Polar H10 (as the reference monitoring device) and the SFH7060 optical sensor. The measured data from the sensor was refined into heart rate information using a Python algorithm, written in order to clean the signal and extract the heartbeat. The sample consisted out of one participant and the research was conducted during March 2022. The results of this study showed that the sensor isn't far off regarding the measurements in comparison to the Polar H10, but the consistency is still a big problem, requiring further research and improvements in both the hardware and software counterparts of the sensor implementation.

Keywords: Data Science, ECG, Heart Monitoring, Heart Rate, Optical Sensors, Osram SFH 7060, Polar H10.

1. Introduction

There are many advancements in the field of optical sensorics, especially when it comes to measuring various biosignals and their derivatives. They pose a multitude of potential benefits compared to the classic medical equipment. Firstly, the hardware solutions tend to be very small, usually in the form of a wristwatch, meaning that they are fully mobile. Secondly, they require a single optical sensor packed into a microcontroller in order to collect the data, which lowers the manufacturing costs compared to the PCBs incorporated into medical equipment. Thirdly, as formerly stated, the data collection occurs in a singular sensor, which removes the need for any external wiring, as it is the case with a Holter monitor. The problem which comes along with this kind of devices is the inconsistent accuracy and the lack of information required for their utilization in medicine. Recently, there have been a few solutions which are more consistent and can provide highly accurate results.

2.1 Heart Rate

Heart rate "is the number of times your heart beats per minute" (American Heart Association, 2015). Furthermore, according to the American Heart Association (2015), the resting heart rate sits between 60 and a 100 beats per minute, which is the reference interval for people who don't have any heart conditions and are sitting or lying down, being in a relaxed state. In this case study the measures which correspond to such conditions were explored, ignoring the cases in which a person is under physical exertion.

2.2 ECG

Measuring heart rate can be done in several ways, though the only device used for medical examinations is called an electrocardiogram. "A surface electrocardiogram (ECG) is a plot of surface bio-potential caused due to electrical activity of the heart. It is a noninvasive tool widely used for many years for basic cardiac monitoring in a clinical set-up" (Chaudhuri et al., 2009, p. 1). There are three types of ECG - a resting ECG, a stress or exercise ECG, and a Holter monitor (Electrocardiogram (ECG), 2021). The resting and stress ECGs are operating in the same way, with a difference of how the test is being conducted. The resting ECG observes a person's heart, as the name suggests, while the person is resting - sitting or lying down. Furthermore, a resting ECG is connected to one's chest, arms and legs via wired electrodes, collecting the signals which are then observed by a medical professional. The stress ECG observes the heart while the person is under physical stress, walking on a treadmill or riding a stationary bicycle, with an addition of observing the blood pressure. The stress ECG has electrodes connected only to one's chest. The Holter monitor is a portable version of an ECG, with its primary use case to collect data in a time span of one to three days. The reason to use it is in cases when the symptoms' occurrences are unpredictable, and therefore cannot be obtained by a resting ECG (Holter Monitor, n.d). This medical ECG type is the one closest to what the wearables utilizing optical sensors are trying to replicate. The electrodes are connected only to one's chest, as with the stress ECG. Mayo Clinic (2022) adds two more ECG types to the list, the Event monitor and the implantable loop recorder. According to the previously mentioned authors, the former is similar to the Holter monitor with an exception that it only records at certain times for a couple of minutes. The latter "is a type of heart-monitoring device that records your heart rhythm continuously for up to three years" (Mayo Clinic, 2022). Mayo Clinic (2022) further states that the implantable loop recorder (additionally called as a cardiac event recorder) is implanted beneath one's chest skin via minor surgery, allowing the medical specialist to remotely monitor one's heartbeat. This type of ECG monitor is also the only intrusive method of heart monitoring, and the only method which has a singular input location. The Polar H10 monitor, used as a reference measuring device, is based on the medical ECG principles and hardware with an exception to being a singular electrode worn over the distal sternum, opposed to having 11 electrodes across the chest, as it is usually the case of the Holter monitor.

2.3 Optical Sensors

LED optical sensors are small electronic devices which consist of two main counterparts, the LED emitter and the photodetector divided by an optical barrier. There are various hardware implementations of such sensors, differentiating in types of light emitters and their amount. There are three commonly used emitters - the green, infrared and red LED emitters. The green light signal is the best choice when it comes to heart rate reading, as it penetrates the skin easily and works with the same efficiency no matter where it is placed on the body. The functional principle is explained in more detail under the Instruments section.

4. Methodology

The goal of this case study was to explore the accuracy of LED optical sensorics in a controlled environment. Obtained research results were then compared to the results obtained from a medically accurate heart rate monitoring device. The sample consisted out of one participant and the research was conducted during March 2022 in the controlled environment, meaning that artificial lights were present during the first measure, and omitted during the second one.The reasoning behind it is that ambient lighting causes interference for the optical sensor, the artificial one having a much larger impact than the natural one. The best results would be obtained by carrying out the measurements in complete darkness, but those conditions were not included in this study, as they don't have a practical use in everyday life (we are talking about 24/7 measuring). The analyzed material consists of two recordings, one in the evening and surrounded by artificial lights, and the second which was done in the morning in a naturally lit environment. The first recording lasted for approximately four minutes, and the second one lasted for approximately ten minutes. The participant wore two instruments at the same time during which the recordings were made.

4.1. Instruments

Instruments used in this research are the Polar H10 heart rate monitor and Osram's SFH7060 heart rate sensor.

Polar H10 heart rate sensor in this research represents a medically accurate heart rate monitoring device. According to the Polar Research and Technology (2019) this is a reliable method for heart rate measurement which was also proven in a couple of scientific studies (Kingsley et al., 2005; Macfarlane et al., 1989). They also state that "In the tests, the H10 sensor together with the Pro Strap has proven to be more accurate than any of the competitor´s strap solutions and also more accurate than any of the Holter monitors tested (Polar Research and Technology, 2019, p. 1). In order to gain the best possible results from the H10 sensor, certain conditions must be met at a high-quality level:

1. "The strap has to fit close to the person, sit comfortably and without moving.

2. The strap must reject electrical disturbances and noise from entering the electrodes.
3. The electrodes on the strap must provide adequate contact to the skin.
4. Signal processing has to detect QRS complex accurately with sub millisecond resolution from the ECG signal.
5. The heart rate calculation algorithm must use state-of-the-art filtering to discard unacceptable readings but allow rapid reaction to changing heart rate" (Polar Research and Technology, 2019, p. 1).

Osram's SFH7060 heart rate sensor in this research represents the LED optical sensor whose accuracy has been tested in this research. Heart rate measurement of this sensor relies on atrial contractions that cause an increase and decrease in blood volume during every heartbeat. "To detect the change in volume caused by the pressure pulse, the skin is illuminated with an LED and the amount of light either transmitted or reflected to a photodetector is measured afterwards" (Retsch & Lex, 2021, p. 3) (Fig 1.).

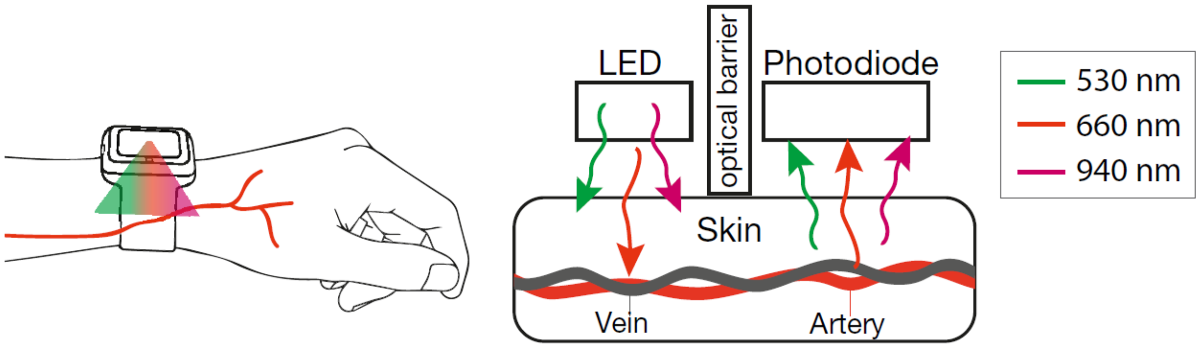

Fig 1. Functional principle for heart rate monitoring (Retsch & Lex, 2021, p. 3)

According to the SFH7060 datasheet (SFH7060, 2016), the sensor contains the three aforementioned emitter types - three green, one red and one infrared emitter. In addition to the emitters, it contains one photosensitive detector. From the available signals, we included only the green one. "Short wavelengths (from blue to yellow) are absorbed strongly. Green is therefore the best choice for heart rate measurement applications, although red and infrared can be successfully used in body locations with a higher concentration of arterial blood (e.g. fingertips, ears, and forehead)" (Retsch & Lex, 2021, p. 3) (Fig 2.).

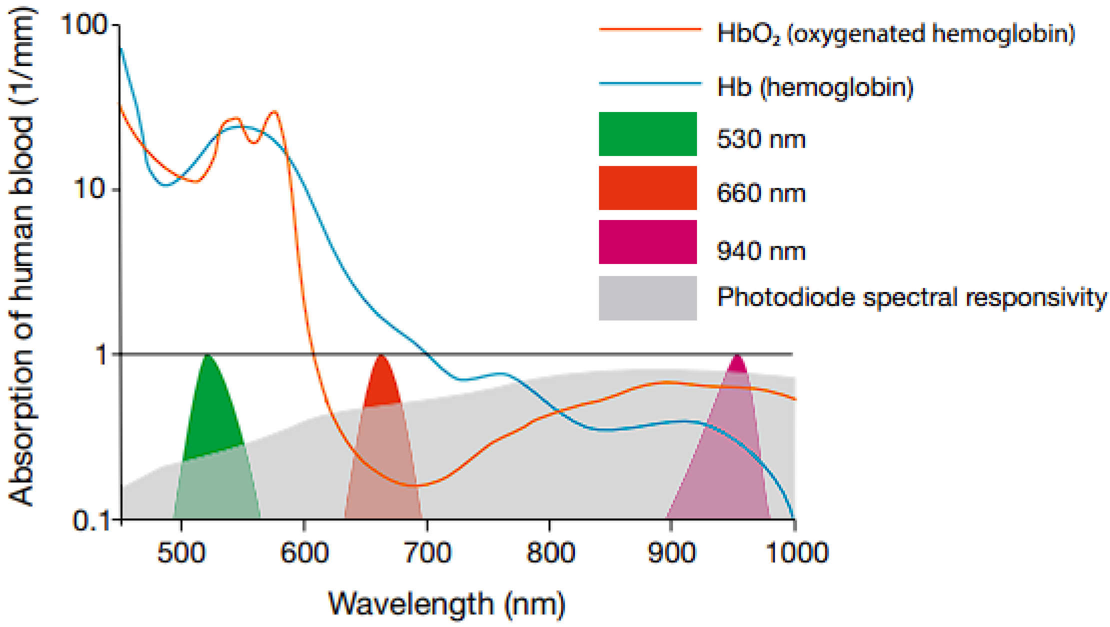

Fig 2. Absorption of human blood versus wavelength of light (Retsch & Lex, 2021, p. 5)

4.2. Heartbeat Data Extraction

After the measurements were recorded, the raw signal data was extracted from the sensor through a Bluetooth connection, and uploaded to a private server instance where all of the recordings are then stored in a csv format. The data was then loaded in a Python script which is responsible for data cleansing and information extraction. Three columns were extracted from the dataset - green, amb_green, and timestamp. Green contains the values representing the captured green wavelength by the photosensitive detector, and amb_green contains the values which are deemed as ambiental interference at the same wavelength. In order to lower the effect of the ambiental lighting, amb_green was deducted from the green values, which then increased the accuracy of further calculations. Timestamp represents the time elapsed, controlled by a 32K oscillator. Since the start time of a recording is known, the first timestamp value was set to zero, and the rest were reduced by the first's original amount. Those values were then divided by 32,768 in order to represent seconds elapsed since the recording started. After this phase the signal values with corresponding times were available for analysis. The second phase was to clean the signal, as it still doesn't represent the actual heartbeat values. To clean the signal, the Fast Fourier Transform (FFT) was performed which resulted in a steady signal with clearly visible peaks, each correlating to a single heartbeat interval. The third and last phase was to count the resulting peaks, in a manner such that at the given time the previous ten seconds were taken as the interval. The total count of peaks for those ten seconds was then multiplied by six, which resulted in a value with a unit of beats per minute.

1. Results

The blue line in Fig 3. represents the heart rate calculations extracted from the SFH7060, while the red one represents the heart rate extracted from the Polar H10.

It is clearly visible that the calculations are in the same range with a small error percentage for most of the time, but there are obvious differences when the optical sensor's error goes up to 8% compared to the H10 calculations.

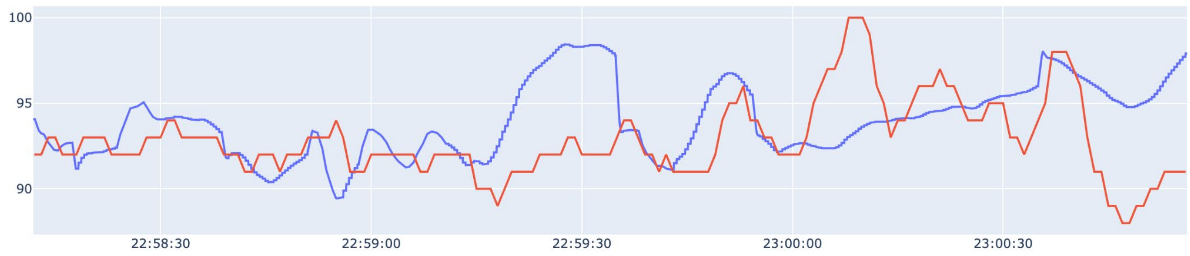

Fig 3. Heart rate comparison with artificial ambient lighting

The green line in Fig 4. represents the heart rate calculations extracted from the SFH7060, while the purple one represents the heart rate extracted from the Polar H10.

The trend of both calculations is quite similar, again with occasional huge differences in the SFH7060 trend. The calculations differ a lot more than they did in the first recording, with an unexpected maximum error of 17%.

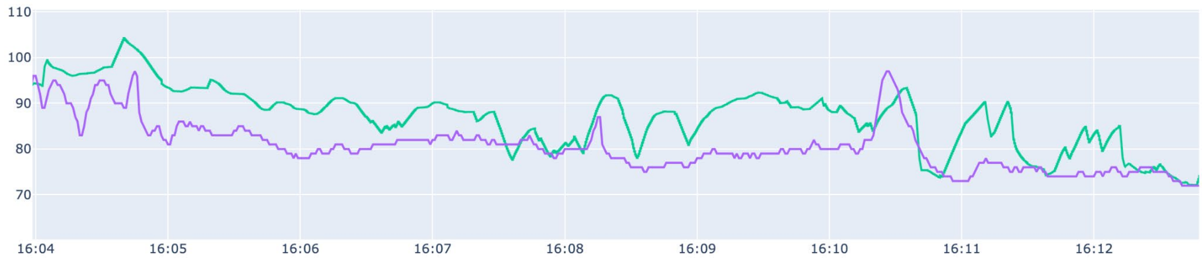

Fig 4. Heart rate comparison with natural ambient lighting

5. Discussion

The SFH7060 sensor proved to be accurate enough for everyday use in the optical sensor solutions' group, but as we can see from the results, it is still quite inconsistent. The SFH7060's trend in the second recording proves that it tends to change the calculations rapidly, even to the point which shouldn't be possible for a measurement of something like a heart rate. The problem is that the ambiental light interferences are something that still has to be overcome in order to increase the measurement consistency. Even though there was an expectation that the second recording would be more precise than the first one, the results surprisingly showed otherwise. That is something that definitely requires further insight, so that the light interference problem solving continues in the right direction. It is possible that some errors exist in the recording due to the small sample size, which is something that will change in the future studies on this matter.

There is still much to resolve in terms of optical sensorics when it comes to reading human biosignals, but we have to take into account that the algorithm used in this study is quite simple. That is why we will continue working on both the tweaks and optimizations of the algorithm, taking into account additional scenarios with a much larger sample size. Additionally, we will perform a comparison of the optical sensor measuring towards the Holter monitor. Some other fields close to this study that are worth exploring are heart rate variability and respiratory rate, which incorporate the aforementioned infrared and red LED emitters in these sensors.

6. References

American Heart Association. (2015, July 31). *All About Heart Rate (Pulse)*. https://www.heart.org/en/health-topics/high-blood-pressure/the-facts-about-high-blood-pressure/all-about-heart-rate-pulse

Chaudhuri, S., Duttagupta, S. & Pawar, T. D. (2008). Introduction. In S. Chaudhuri, T. D. Pawar & S. Duttagupta (Eds.), *Ambulation Analysis in Wearable ECG* (pp. 1-13). Springer. https://doi.org/10.1007/978-1-4419-0724-0

Electrocardiogram (ECG) (2021, September 7). National Health Service. Retrieved March 16, 2022, from https://www.nhs.uk/conditions/electrocardiogram/

Holter Monitor (n.d.). Johns Hopkins Medicine. Retrieved March 15, 2022, from https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/holter-monitor

Kingsley, M., Lewis, M. & Marson, R. (2005). Comparison of Polar 810s and an ambulatory ECG system. *International Journal of Sports Medicine, 26*, 39-43.

Macfarlane, D.J., Fogarty, B.A. & Hopkins W.C. (1989). The Accuracy and Variability of commercially Available Heart Rate Monitors. *The New Zealand Journal of Sports Medicine, 17*(4), 51-53.

Mayo Clinic. (2022, March 19). *Electrocardiogram (ECG or EKG)*. Retrieved March 20, 2022, from https://www.mayoclinic.org/tests-procedures/ekg/about/pac-20384983

Polar Research and Technology. (2019). *Polar H10 Heart Rate Sensor System*. [White paper]. Polar. https://www.polar.com/sites/default/files/static/science/white-papers/polar-h10-heart-rate-sensor-white-paper.pdf

Retsch, S. & Lex, F. (2021). *Health monitoring*. Osram-os. https://dammedia.osram.info/media/resource/hires/osram-dam-13961896/Health%20monitoring.pdf

SFH7060 (2016, April 20). OSRAM. OSRAM Opto Semiconductors GmbH. Retrieved March 14, 2022, from https://dammedia.osram.info/media/resource/hires/osram-dam-2496436/SFH%207060_EN.pdf