# OPTICAL SENSING OF MUSCLE ACTIVITY

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## ABSTRACT

In recent years there has been an increasing interest in alternative muscle sensing methods. Optical myography is a relatively new field in muscle sensing techniques, which uses light to detect variation in the shape underlying muscle as it is contracted. We investigated the effect of finger motion and sensor placement on the resulting optical signal and compared it to clinical electromyography. Evidence suggests that the optical signal is strongly correlated to muscle activity and has high spatial accuracy.

## INTRODUCTION

In upper-limb prosthetics research, methods of recording changes in muscle activity are commonly based on Electromyography (EMG), Mechanomyography and Sonomyography. Despite their attractive qualities, these sensors have limitations such as susceptibility to electrical noise, the influence of sweat, relatively high costs, and power requirements. An alternative approach known as 'optical myography', has gained increased interest in recent years [1, 2]. Typically, optical sensing involves shining a near-infrared (NIR) light source on the surface of the skin. The light travels through the derma, lipids, blood vessels and is partially reflected by the muscle's surface back to a photoreceiver. Contractions alter the geometry of the muscle which impact the intensity of light incident at the receiver. This can then be used to estimate muscle activation. This approach is like plethysmography (PPG) which estimates blood oxygenation. In contrast to PPG, rather than treating movement artefacts as noise, optical myography actively utilises this information. Exploring muscle activation from the optical domain introduces certain advantages. For example, while surface EMG captures the superposition of electrical activity over a given area, optical sensing may produce a finer spatial resolution, only detecting movement from areas below the photoreceiver [3]. However, being a less mature approach, the technique is not yet well understood [4]. We developed an NIR acquisition system to track subcutaneous changes from forearm muscles. The aim of this research was to explore the properties of optical myography and to investigate the relationship between sensor location and finger movement detection.

## METHODS

We conducted two experiments involving closed-loop control of a one degree-of-freedom cursor via finger flexion Experiment A was run to characterise the response of the optical sensor across the lower arm of a single limb-intact participant. The optical data were compared to ground truth finger flexion data and gold standard EMG data. The aim of Experiment B was to investigate the relationship between finger flexion and optical signal response and to what degree individual fingers can be differentiated from one another.

### Participants

Experiment A: One limb intact participant (male, 25 years old). Experiment B: 11 limb-intact participants (20-30 years old). All participants were free of any neurological or motor impairments and provided written informed consent. Ethics for this experiment was provided by the local committee at Newcastle University (Ref: 21-029-FRA).

Sensor design

Two LEDs at 640 nm and 850 nm are used as low-power emitters. The receiver consists of a photodiode (PD) and a transimpedance amplifier to convert the current generated into voltage. The analogue output is fed to a microcontroller which digitises the signal and relays it over a serial connection.

Recordings

**Finger position:** In experiment A, a flexible capacitive sensor (Bend Labs, Japan) was fixed on the middle finger providing the ground truth, the sensor was sampled at 500 Hz. In Experiment B, an infrared hand-tracking camera sensor (Leap Motion Controller, Ultraleap, USA) was used as the ground truth, approximating finger joint position at a sampling rate of 48 Hz. The Leap Motion sensor was placed on a desk around ~40 cm from the participant hand.

**Electromyography:** Two Trigno EMG sensors (Delsys, USA) were placed over the flexor carpi radialis (FCR) and muscle group and two sensors were placed over the extensor carpi radialis (ECR) muscle group. Sensors were sampled at 2000 Hz. Electromyography sensors were only used in Experiment A.

**Optical:** The optical sensor was mounted on the surface of the arm using an elastic strap. Note, there was no intentional air gap between the emitter-receiver components and the skin. The wavelength of light used during the experiments was 850 nm and the data was sampled at a rate of 500 Hz.

Protocol

Two experiments were performed. Experiment A recorded a high-density mapping of the participant's arm using the optical sensor. Experiment B explored how finger activity influences the optical signal acquired in a region around the wrist area. The participant sat in a comfortable position with their right arm and elbow supported. The participant was then shown the experimental task on a computer screen. The task consisted of a target moving up and down, following a cosine function. Finger position controlled the vertical height of a cursor on the screen. The goal was to keep the cursor inside the moving target.

**Experiment A:** The middle finger was placed inside an adapter ring which transferred the movement to the flexible sensor. Each trial lasted 10 seconds, with the vertical height of the target making one full cycle. There were 10 trials for each block. At the end of a block of trials, the sensor was moved to a new position on a 10 by 12 matrix. This approach was used to iteratively image the arm using a single channel sensor.

**Experiment B:** Participants were asked to follow the task on the monitor. At all times the silhouette of a hand highlighted which finger was to be moved during the trial. After 5 trials the participant was prompt by an image to use the next finger. Fingers were tested in order: Index, Middle, Ring and Pinky. After a block was completed, the optical sensor was moved along a row of 10 positions from the inside to the outside of the arm, at a distance around 4 cm from the wrist. The distance between each position was 1 cm.

Statistical analysis

**Experiment A:** Muscle activity was calculated using the mean absolute value (MAV) of the raw EMG output. A correlation value for each sensor position against the optical signal was estimated. This results in a 12x10 matrix, which was interpolated by a factor of 7. Correlation values were calculated for each sensor position over two windows, corresponding to flexion and extension of the finger. Correlation between optical and flex data were calculated trial by trial, and the mean correlation calculated.

**Experiment B:** The optical signal obtained during flexion and extension of the index finger was compared to that obtained during movement of the middle finger. A Bonferroni corrected statistical analysis was run, correcting for three comparisons. The calculation was performed over a period corresponding to peak flexion of the finger.

## RESULTS

The results of Experiment A are shown in Figure 1. The block average was plotted to account for small variations in the participant performance, expected between trials. Some high frequency noise is showed in the EMG sensors, whereas the optical sensor shows environmental light switching frequencies (~100 Hz) and motion artifacts from changes in blood flow. As shown in Figure 1, the optical sensor output at distinct sensor sites is highly correlated to

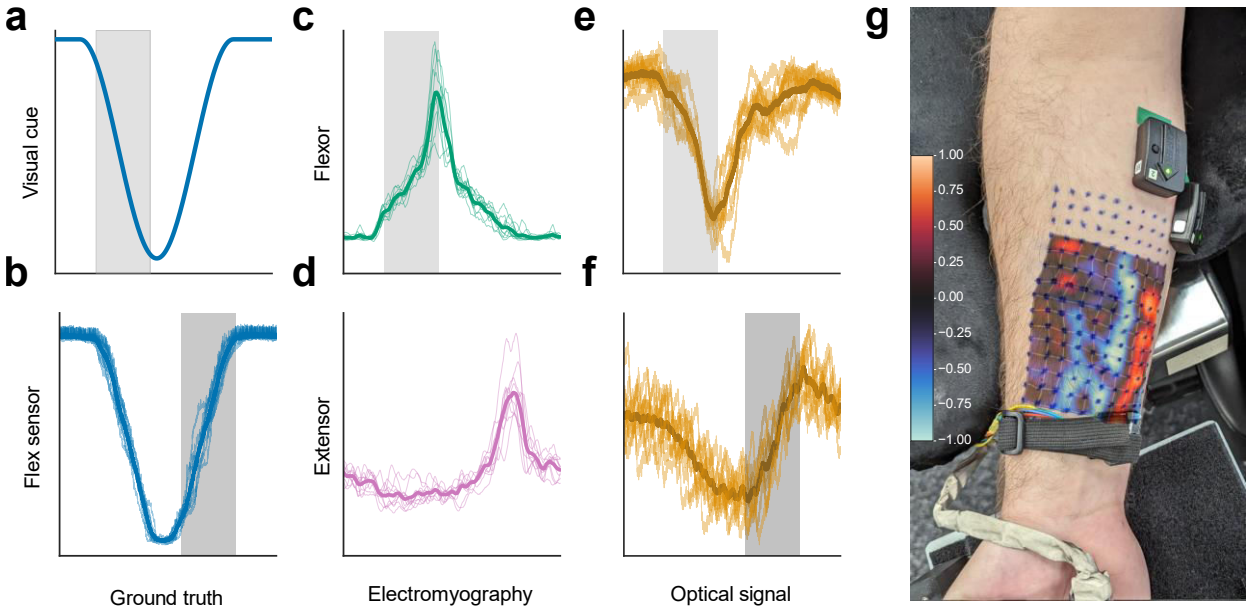


Figure 1: Exemplar timeseries of the sensors' output. The two time periods of interest are highlighted. Light grey indicates finger flexion, dark grey indicates extension. (a) Visual prompt for the participant. (b) Flex sensor providing the data for the ground truth. (c) & (e) Timeseries plots corresponding to the period of maximum negative flexor use correlation across the MAV from the EMG Flexor sensor, and the optical sensor, respectively. (d) & (f) timeseries analysis on the period of maximum positive correlation of respectively, the MAV of the EMG extensor, and the optical sensor. (g) Experiment A setup with resulting optical against flex sensor correlation heatmap conformed to participant arm. Axis intersections represent probe points, as indicated on the participant's arm.

the EMG envelope associated with flexion and extension of the finger. The arm image in Figure 1g indicates in red where a positive correlation exists between the optical signal and the flex sensor during flexion of the finger, suggesting a high degree of spatial acuity over the flexor muscle and tendons. A negative correlation is noted directly adjacent to the positive correlation, likely to also reflect muscle displacement. The intersection between the row and columns are indicative of the sensor position.

The results of experiment B are shown in Figure 2. An example showing the sensor tape guide in show in Figure 2a. The marks are posed 1 cm apart and indicated sensor positions to test. Note that 9 and 10 are wrapped around and are not visible in the image. The statistical significance map in Figure 2b estimates where statistical differences exist between activity produced by individual fingers, in this case the Index-Middle finger combination, across the ten sensor locations for each participant. Several areas reach statistical significance, predominantly on the ventral side of the arm towards the ulna. These are not limited to the inner portion of the wrist.

## DISCUSSION

Slow variations in the optical sensor output are attributed to oxygen levels in the muscle tissue varying after repetitive activations. The timeseries shown in Figure 1 demonstrate that with appropriate filtering, this has relatively little impact on the ability of the optical sensor to sample the underlying muscle activity, with an accuracy comparable to the flex sensor and electromyography. Blood flow appears to be the larger source of noise in optical systems as presented in the timeseries. Since the cosine wave used as visual prompt in these experiments was relatively slow (0.14Hz), we anticipate a higher relative signal power for more rapid movements, with a bandpass filter appropriate to decrease blood flow artefacts.

Figure 1d shows EMG corresponding to participants use of antagonist muscles to bring the finger to a relaxed or straight position. It is interesting to note that the optical sensor produces a similar signal, Figure 1f, on the inner arm.

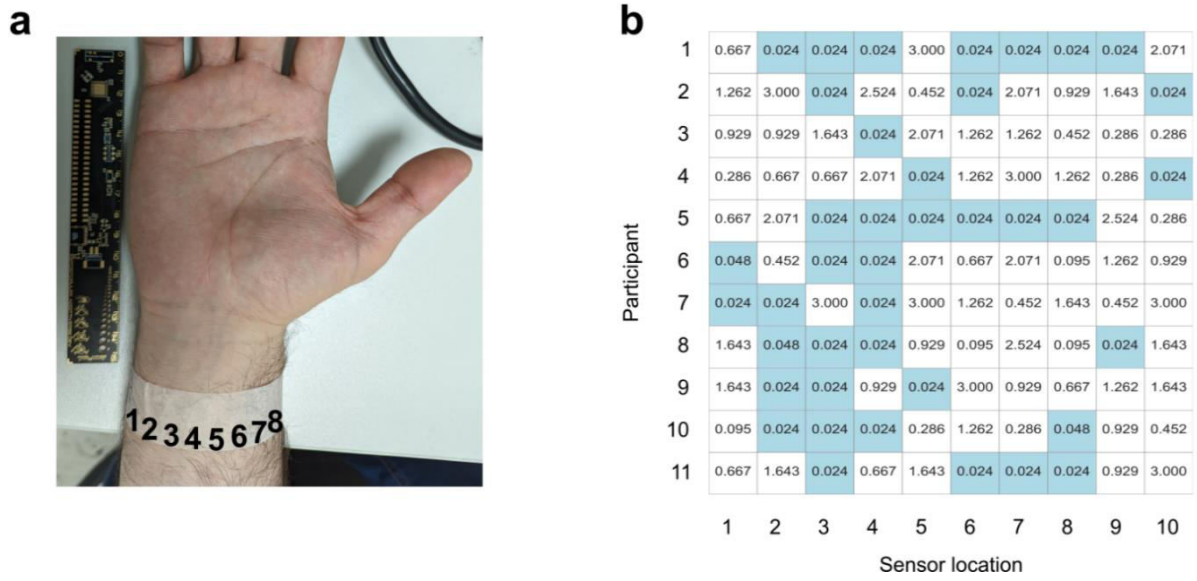


Figure 2: (a) Sample image showing sensors locations. (b) Bonferroni corrected statistical significance map showing where Index-Middle finger activity is significantly different ($p < 0.05$) at each sensor position across participants. The numerical value represents the Bonferroni statistical significance for the finger pair. Blue indicates statistical significance.

We assume this corresponds to the extensor group muscle returning from a contracted position back to a relaxed one. The correlation image shown in Figure 1g shows an extended area of positive correlation which may coincide with flexor digitorum superficialis. An area of inverted correlation lies directly adjacent to this area, it is possible that this corresponds to muscle moving away from the sensor as a contraction is made. The results presented in Figure 2 suggest activation from individual fingers are likely to be distinguishable using optical sensing. Most sites are located on the ventral side of the arm towards the ulna, again corresponding broadly to flexor digitorum superficialis. This muscle group is likely to play a role in the significance map, because it extends primarily on the inner and middle side of the forearm. We note quite a high variance between participants which may be connected to the individual biological differences in arm size and also of fat tissue. The conclusions which we can draw from an analysis based on a single sensor are however, limited. Future studies will utilise an increased density of sensor sites to ascertain more information about the spatial resolution of optical sensing. In a separate study we are utilising faster contracts to investigate how the signal changes compared to muscle activation, and we are also characterising how skin tone and other physiological factors impact on sensor output [5].

## ACKNOWLEDGMENTS

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