

## CAPACITIVE FACIAL ACTIVITY MEASUREMENT

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**Abstract:** A wide range of applications can benefit from the measurement of facial activity. The current study presents a method that can be used to detect the movements of different parts of the face and expressions that they form. The method is based on capacitive measurement of facial movements and utilisation of principal component analysis on the measured data to identify active areas of the face. Experiments involving a set of voluntary facial movements were carried out with 10 participants. The results show that the method could be applied to locating facial activity during movements such as raising and lowering eyebrows, opening mouth, raising mouth corners, and lowering mouth corners.

**Keywords:** Capacitive measurement, distance measurement, facial activity measurement, facial movement detection, principal component analysis

### 1. INTRODUCTION

Measuring facial movements has many possible applications. Human-computer and human-technology interaction (HCI and HTI) can use information of voluntary facial movements for the interaction. Other applications can also benefit from the automated analysis of human facial movements and expressions.

In the context of HCI, the use of facial movements has been studied already for a decade. The first implementations were based on measuring electromyographic (EMG) signals that reflect the electrical activity of the muscles [1]. The measurement system by Barreto et al. [1] utilised only bioelectric signals for pointing and select-

ing objects, but later on EMG measurement was adopted as a method to indicate selections in HCI where gaze is used for pointing [2, 3, 4, 5]. Recently, a capacitive detection method has been introduced as an alternative for the facial EMG measurement [6]. It provides a contactless alternative that measures facial movement instead of the electrical activity of the muscles that EMG measures. Studies about pointing and selecting with the capacitive method in combination with head-mounted, video-based gaze tracking have been also published [7, 8, 9].

Facial Action Coding System (FACS) is a method that characterizes facial actions based on the activity of different facial muscles [10, 11]. Each facial expression has certain activated muscles that can have different levels of contraction. FACS and the detection of active muscles can be used as a basis for automatically analysing facial expressions for different application areas, such as behavioural science [12] and neuropsychiatry [13]. These studies use vision-based methods in the analysis, but facial EMG has also been shown to be suitable for measuring emotional reactions from the face [14]. This has been done long before EMG has been applied in the HCI context to detect voluntary facial movements.

The presented method applies capacitive measurement principles to measure the activity of the face. It has several advantages over other methods that can be used for the task. Compared to EMG measurements, the presented method allows the measurement of more channels simultaneously. It is contactless, and thus it does not require the attachment of electrodes to the face. Attached electrodes significantly limit the maximum number of measurable channels and they may also affect facial movements that are being targeted with the mea-

surement. When compared to vision-based detection of facial activity, the capacitive method allows easier integration of the measurement to mobile, head-worn equipment, is unaffected by environmental lighting conditions, and can be expected to be carried out with computationally less intensive signal processing.

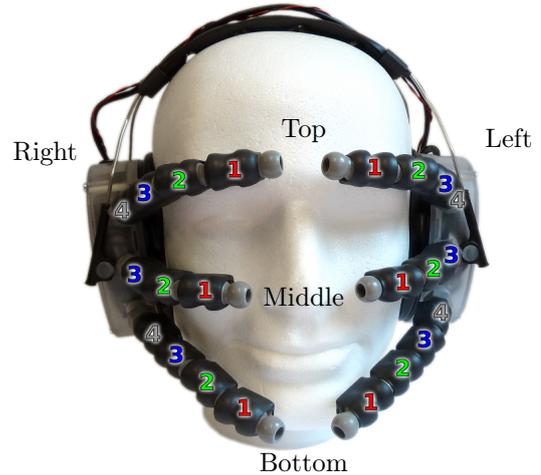
For the current study, a wireless, wearable prototype device was constructed, and analysis of data from controlled experiments was done to identify the location of facial activity during different voluntary movements. Voluntary facial gestures have previously been detected by identifying transient peaks from the signals [6]. The presented method provides a more robust way to analyse the facial activity based on multichannel measurements.

## 2. METHODS

**Capacitive Facial Movement Detection:** The measurement method for measuring facial activity is based on the capacitive detection of facial movements that was introduced in [6]. The measurement applies the same measurement principle as capacitive push buttons and touchpads, and a single measurement channel requires only a single electrode that produces an electric field. The produced field can be used to detect conducting objects in its proximity by measuring the capacitance because the capacitive coupling between the electrode and the object changes as the object moves. In principle, the measurement is a distance measurement between the target and the electrode.

**Prototype Device:** The wearable measurement prototype device is shown in Fig. 1. The device was constructed as a headset. The earmuffs of the headset house the necessary electronics, and the extensions seen in front of the face include the electrodes for the capacitive measurement channels. There are 22 electrodes in total, 11 for both sides of the face. The topmost extensions have 4 electrodes each, the middle ones have 3 each, and the lowest ones have 4. The electrodes are printed circuit board pieces with a size of 12 x 20 mm. They are connected to the measurement electronics with thin coaxial cables that shield the signals. The capacitive measurements are carried out with a programmable controller for capacitance touch sensors (AD7147 by Analog Devices). The sampling frequency was dictated by technical limitations and it was set to the maximum possible, 29 Hz. The device is battery-powered and a Bluetooth module (RN-41 by Roving Networks) provides the connectivity to the computer. The device has the possibility for additional measurements such as inertial measurements via a 3D gyroscope and a 3D accelerometer. The operation of the device is controlled by Atmel’s ATmega168P microcontroller.

**Experiments:** Ten participants, five male and five female, inexperienced in doing voluntary facial movements



**Figure 1:** The wearable measurement device. The numbers represent the extension pieces that house the measurement electrodes. The actual electrode locations are on the pieces facing the face.

were briefly trained to perform a set of voluntary facial movements. The movements were: lowering the eyebrows, raising the eyebrows, closing the eyes, opening the mouth, raising the mouth corners, lowering the mouth corners, and relaxation of the face. The relaxation was included to help the participant relax during the experiments while doing the other movements. The movements were instructed to be performed according to the FACS [11]. The participants were instructed to activate only the needed muscles during each of the movements. After a brief practise period and verification that the participant made the movements correctly, the device was worn by the participant as shown in Fig. 1: the top extensions targeted the eyebrows, the middle ones the cheek areas, and the bottom ones the jaw and mouth area. The distance of each of the measurement electrodes from the facial tissue was adjusted to be as close as possible without the electrodes touching the face during the movements. This way the distance was approximately 1 cm for all locations. In the experiments, synthesized speech was used to give instructions to the participants to perform each individual movement. After putting on the device, two repetitions of each of the movements were carried out in a controlled practise session to familiarise the participants with the experimental procedure. Finally, the actual procedure was started. Ten repetitions of each movement were carried out in randomized order. A mirror was used throughout the experiments to provide visual feedback of the facial movements to the participants.

**Data Processing:** First the capacitive signals were converted to signals proportional to the physical distance between the facial tissue and the measurement electrode. The conversion normalises the sensitivity of the measure-

ment to the distance. The capacitance measurement was modelled with the equation for parallel plate capacitor:

$$C = \frac{\epsilon A}{d}, \quad (1)$$

where  $\epsilon$  is the permittivity of the substance between the plates,  $A$  the plate area, and  $d$  the distance between the plates. One plate is formed by the measurement electrode and the other by the targeted facial tissue. While the surface profile of the facial tissue is often not a plate, each unique profile can be considered to have such an equivalent plate that the equation holds. Since the relationship between the capacitance and the distance is inversely proportional, the sensitivity of the capacitance to the distance is dependent on the distance itself. The absolute distance is not of interest, and a measure proportional to the distance can be calculated as

$$d_p = \frac{1}{C} = \frac{1}{C_s - C_b}, \quad (2)$$

where  $C_s$  is the value of the measured capacitance sample and  $C_b$  is the base level of the capacitance channel. Each channel has a unique base level that is affected by the length of the electrode cable and the surroundings of the electrode determined by its position on the extension. For the conversion, the base levels of all the capacitance channels were measured when the measurement electrodes were directed away from conducting objects.

After converting the capacitance signals, they were processed with a moving median filter with a length of 35 samples (approximately 1.2 seconds) to remove noise. Further, the signals were normalised by removing their means during each repetition of the instructed movements. The resulting signal sequences are proportional to relative changes in the physical distance.

Principal component analysis (PCA) was carried out to the preprocessed signal sequences to find out the locations of the facial activity during the instructed facial movements. PCA is a linear method which transforms a data matrix with multiple variables, measurement channels in this case, to a set of uncorrelated components [15]. These principal components are linear combinations of original variables and they describe the major variations in the data. PCA decomposes the data matrix  $\mathbf{X}$ , which has  $m$  measurements and  $n$  channels, as the sum of the outer product of vectors  $\mathbf{t}_i$  and  $\mathbf{p}_i$  and residual matrix  $\mathbf{E}$ :

$$\mathbf{X} = \mathbf{t}_1 \mathbf{p}_1^T + \mathbf{t}_2 \mathbf{p}_2^T + \dots + \mathbf{t}_k \mathbf{p}_k^T + \mathbf{E}, \quad (3)$$

where  $k$  is the number of principal components used. If all possible components are used, the residual reduces to zero. Vectors  $\mathbf{t}_i$  are called scores, and  $\mathbf{p}_i$  are eigenvectors of the covariance matrix of  $\mathbf{X}$  and are called loadings. The principal components are ordered according to the corresponding eigenvalues.

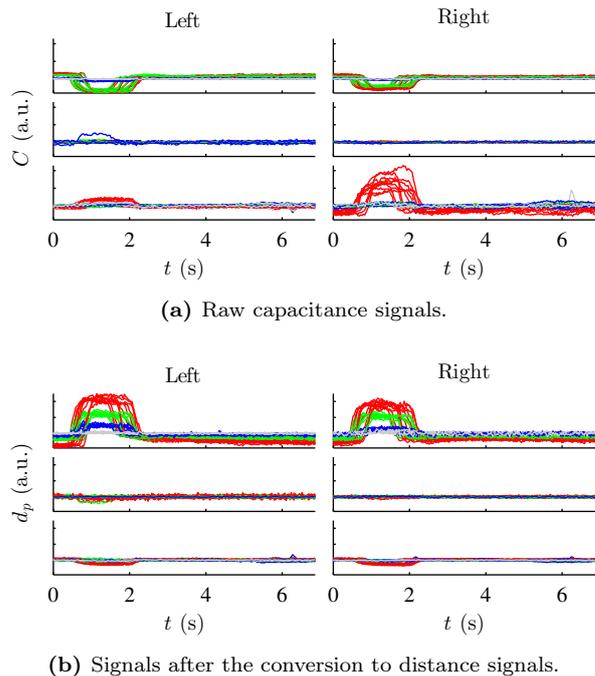
To localise facial activity, the first principal component and its loadings were considered. The first principal component describes the major data variations, and thus the location of the most significant facial activity can be

identified by analysing the loadings of the measurement channels with respect to it.

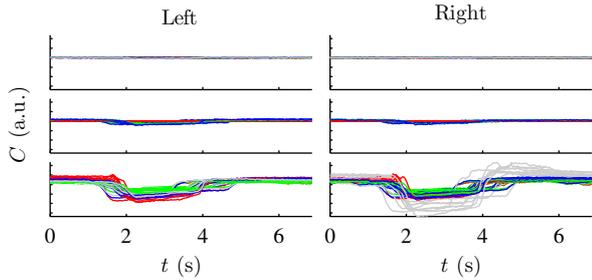
To present the results, the vertical location of each repetition of the movements was mapped to the part of the face that introduced two of the three most significant loadings of the first principal component. For calculating percentages of successful mappings, the correct source of activity was considered to be the top extension channels for the lowering and raising eyebrows as well as the closing eyes movement, the bottom extension channels for the opening mouth and lowering mouth corners movements, and the middle or bottom extension channels for the raising mouth corners movement. Median loadings of the 10 repetitions of each movement were calculated for each participant and channel separately to verify the decisions about the correct sources of activity.

### 3. RESULTS AND DISCUSSION

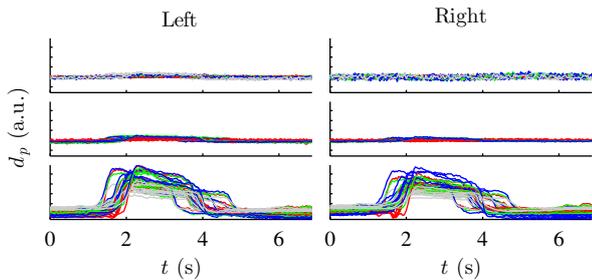
Fig. 2 and 3 show examples of the signals the measurement channels registered during the experiments and how the conversion from capacitance signals to ones that are proportional to the distance normalises the signals.



**Figure 2:** Signals from the 10 repetitions of the raising eyebrows movement with one participant. The different sides of the face are represented on the left and on the right. The top, middle, and bottom graphs represent the measurements from the corresponding extensions. The colours represent the different channels as shown in Fig. 1: red, green, blue, and grey starting from the centre of the face. Signal baselines are aligned for the illustration.



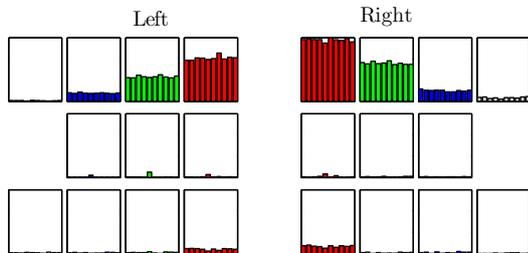
(a) Capacitance signals.



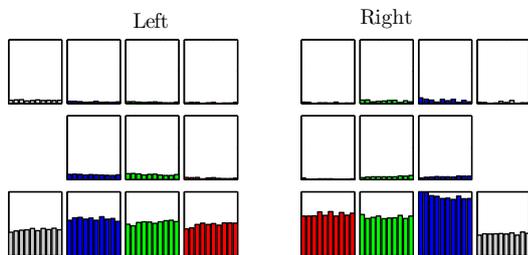
(b) Signals after the conversion to distance signals.

**Figure 3:** Signals from the 10 repetitions of the opening mouth movement with one participant. See Fig. 2 for explanation of the presentation.

Examples of the detected facial activity presented as the loadings of the first principal component are shown in Fig. 4.



(a) The raising eyebrows movement.



(b) The opening mouth movement.

**Figure 4:** Examples of the facial activity as represented by the loadings of the first principal component during the movements with single participants. Each graph represents the loadings of the 10 repetitions from the measurement channel of the corresponding physical location.

The performance of locating the different movements is presented in Table 1.

**Table 1:** The percentages of successful mapping of the vertical location of the movements. The last row shows the means and standard deviations for the movements.

| Part-<br>ici-<br>pant | Lowering<br>eye-<br>brows | Raising<br>eye-<br>brows | Closing<br>eyes | Opening<br>mouth | Raising<br>mouth<br>corners | Lowering<br>mouth<br>corners |
|-----------------------|---------------------------|--------------------------|-----------------|------------------|-----------------------------|------------------------------|
| 1                     | 100                       | 90                       | 50              | 100              | 100                         | 100                          |
| 2                     | 100                       | 100                      | 60              | 100              | 100                         | 100                          |
| 3                     | 100                       | 100                      | 90              | 100              | 100                         | 100                          |
| 4                     | 100                       | 100                      | 100             | 100              | 100                         | 100                          |
| 5                     | 100                       | 100                      | 30              | 100              | 100                         | 100                          |
| 6                     | 100                       | 100                      | 100             | 100              | 100                         | 100                          |
| 7                     | 100                       | 100                      | 40              | 100              | 100                         | 100                          |
| 8                     | 90                        | 100                      | 80              | 100              | 100                         | 100                          |
| 9                     | 100                       | 100                      | 100             | 100              | 100                         | 60                           |
| 10                    | 100                       | 100                      | 80              | 100              | 100                         | 100                          |
| Mean                  | 99 ± 3                    | 99 ± 3                   | 73 ± 26         | 100 ± 0          | 100 ± 0                     | 96 ± 13                      |

Out of the 6 included voluntary movements, opening mouth and raising mouth corners are located correctly in all the repetitions with all participants. Lowering eyebrows and raising eyebrows are located correctly in almost all the repetitions with all participants. Only a single repetition of both is incorrectly located. Lowering mouth corners is correctly located except for 4 repetitions with a single participant. Closing eyes has a limited success rate in the mapping with 7 out of 10 participants.

The locations of the three measurement channels that registered the most significant activity during the experiments according to the median loadings are presented in Table 2. The locations can be used as a basis for mapping the movements as was done with the presented vertical location mapping. The table also verifies that the decisions regarding the correct sources of activity were justified according to the used order statistic, the median.

Incorrectly detected activity can be a result of several factors. Firstly, the participants could not always carry out the movements exactly as instructed, but some unintentional activity of other muscles was included. Secondly, the measurement and the applied data processing both are slightly sensitive to the movement of the prototype device on the head. This may result in false detection of activity when the device moves instead of the facial tissue. Thirdly, including only one principal component may limit the performance of locating the activity. The amount of the variance explained by the first principal component was not analysed in this study, but it could be used to provide an estimate of the certainty in locating the activity. More principal components could be added to the analysis to increase the certainty. Finally, the mentioned error sources are also affected by the noise in the measurement. The noise is dependent on the distance of the measurement electrodes from the target. The current implementation normalises the signal levels, but the normalisation also scales the noise

**Table 2:** The locations of the three measurement channels that had the most significant impact on the measured facial activity as indicated by the median loadings of the respective first principal components during the movements. The locations and numbers correspond to the locations and numbering in Fig. 1. The *italic* type indicates measurement channels that have significant facial activity in movements in which they should not have.

| Participant | Lowering eye-brows                          | Raising eye-brows                                    | Closing eyes  | Opening mouth  | Raising mouth corners                                | Lowering mouth corners                               |
|-------------|---|--|---|--|--|--|
| 1           | top right 1,<br>top left 1,<br>top right 2  | top right 1,<br>top left 1,<br><i>bottom right 1</i> | top right 1,<br>top left 2,<br><i>bottom right 3</i>            | bottom right 3,<br>bottom right 2,<br>bottom right 1 | bottom right 1,<br>bottom right 3,<br>bottom left 1  | bottom right 3,<br>bottom right 2,<br>bottom right 1 |
| 2           | top left 1,<br>top right 2,<br>top right 3  | top right 1,<br>top left 1,<br>top right 2           | top right 3,<br>top right 1,<br><i>middle right 1</i>           | bottom right 3,<br>bottom right 2,<br>bottom right 1 | middle right 1,<br>middle right 2,<br>middle left 2  | bottom left 3,<br>bottom right 3,<br>bottom left 4   |
| 3           | top right 1,<br>top left 1,<br>top right 3  | top right 1,<br>top right 2,<br>top left 1           | top right 2,<br>top left 2,<br>top left 1                       | bottom right 3,<br>bottom right 1,<br>bottom right 2 | middle right 1,<br>middle left 1,<br>bottom right 1  | bottom right 1,<br>bottom right 3,<br>bottom right 2 |
| 4           | top right 1,<br>top left 1,<br>top right 2  | top right 1,<br>top right 2,<br>top left 1           | top right 1,<br>top right 2,<br>top left 1                      | bottom right 3,<br>bottom right 1,<br>bottom left 3  | middle right 1,<br>middle left 1,<br>middle right 2  | bottom left 2,<br>bottom right 2,<br>bottom left 3   |
| 5           | top left 2,<br>top right 1,<br>top right 2  | top right 1,<br>top left 1,<br>top right 2           | <i>bottom right 1</i> ,<br>top right 1,<br><i>bottom left 2</i> | bottom right 1,<br>bottom right 2,<br>bottom right 3 | bottom right 1,<br>middle right 1,<br>bottom right 3 | bottom left 1,<br>bottom right 1,<br>bottom left 2   |
| 6           | top right 2,<br>top left 2,<br>top right 3  | top right 1,<br>top right 2,<br>top left 2           | top right 1,<br>top right 3,<br>top right 4                     | bottom right 3,<br>bottom right 2,<br>bottom right 1 | middle right 1,<br>bottom right 1,<br>middle right 2 | bottom right 3,<br>bottom right 1,<br>bottom left 3  |
| 7           | top right 1,<br>top right 2,<br>top left 2  | top right 1,<br>top left 1,<br>top right 2           | top right 1,<br>top right 2,<br><i>bottom right 2</i>           | bottom right 1,<br>bottom right 2,<br>bottom right 3 | bottom right 1,<br>bottom left 1,<br>bottom left 3   | bottom right 2,<br>bottom right 1,<br>bottom right 3 |
| 8           | top right 2,<br>top left 2,<br>top right 3  | top right 1,<br>top right 2,<br>top left 1           | top right 2,<br>top right 1,<br>top left 1                      | bottom right 1,<br>bottom right 3,<br>bottom right 2 | middle right 1,<br>middle right 2,<br>middle left 1  | bottom right 1,<br>bottom right 2,<br>middle right 1 |
| 9           | top right 1,<br>top left 1,<br>top right 2  | top right 2,<br>top right 1,<br>top right 3          | top right 2,<br>top left 2,<br>top right 1                      | bottom left 1,<br>bottom right 1,<br>bottom right 3  | middle right 1,<br>middle right 2,<br>bottom right 2 | bottom right 1,<br>bottom right 2,<br>middle right 1 |
| 10          | top right 2,<br>top right 3,<br>top right 1 | top right 2,<br>top right ,<br>top left 2            | top right 3,<br>top right 4,<br>top right 2                     | bottom right 3,<br>bottom right 1,<br>bottom right 2 | middle right 1,<br>middle left 2,<br>bottom left 2   | bottom right 2,<br>bottom right 1,<br>bottom left 2  |

so that measurements with the facial tissue further away from the measurement electrode include more noise than when the tissue is closer. With additional pre-processing, the effect of the noise could be cancelled out.

#### 4. CONCLUSION

A new method for mobile, head-worn facial activity measurement was presented. The capacitive method and the prototype constructed for studying it were shown to perform well in locating different voluntary facial movements to the correct areas on the face based on principal component analysis of the measured signals. The method has clear benefits when compared to computationally more intensive vision-based methods and EMG that requires attachment of electrodes on the face.

Future research on the method is required to develop signal processing methods to detect and classify facial activity in real-time for human-technology interaction contexts and in behavioural analysis of the user. In the former, voluntary and even involuntary gestures and ex-

pressions could be detected and used as control signals. Behavioural analysis would benefit from the identification of more complex facial expressions, i.e. the combinations of activity at different locations on the face. Furthermore, determining the intensity level of the activity of different facial areas could provide additional information. It could be studied how different activation levels can be distinguished from one another with the presented method.

#### ACKNOWLEDGEMENTS

The authors would like to thank Nokia Research Center and the Finnish Funding Agency for Technology and Innovation (Tekes) for funding the research and Nokia Foundation for supporting it.

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