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A facegram for spatial–temporal analysis of facial excursion: Applicability in the microsurgical reanimation of long-standing paralysis and pretransplantation

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ABSTRACT

Background: There are several techniques available for facial reanimation, but clinicians do not have a simple tool to provide an objective and quantitative spatial–temporal analysis of facial movement in order to compare medical, surgical and physical therapy.
Methods: We developed specialized software capable of simultaneously tracking the position over time of a number of anatomical points. This method was tested in 5 different clinical situations: one normal subject, and 4 patients with facial disfigurement.
Results: A large amount of quantitative information can be extracted directly, such as symmetry assessment in the contraction and relaxation trajectories. The fact that this plot is on scale allows also direct measurements such as maximal extensions. Even smiles that at the macro-scale are essentially symmetrical show at the micro-scale small asymmetries/variability.
Conclusion: In this paper, we describe a novel quantitative, reliable method, which accurately assesses the fundamental aspects of the facial excursion, incorporating spatial and temporal components.

1. Introduction

The goal of facial reanimation is restoration of both a symmetric face at rest and a spontaneous smile. There are several techniques available for facial reanimation. These include reinnervation techniques, muscle transfers, and static procedures.

An essential element to support and, more importantly, assess the reanimation techniques is the precise measurement of static and dynamic facial features. There are simple methods to assess oral excursion, but they lack some objectivity and standardization (Manktelow et al., 2008). Quantitative methods have been developed but require equipment that usually includes video cameras, a complex calibration device, computer customized software, IR lightings to illuminate the face and minimise the effect of varying lighting conditions (Sjögreen et al., 2011; Frey et al., 1999). Although three-dimensional tracking can provide enhanced information, analysis is time-consuming, expensive, requires complex equipment such as special lighting, the use of reflective markers a dense array of cameras, and the person operating the system has to have thorough education and experience, which may reduce the utility of these methods for clinical assessment.

Clinicians do not have a simple tool providing an objective and quantitative analysis of facial movement in order to compare medical, surgical and physical therapy. Such a tool necessarily involves the acquisition of two-dimensional (2D) or three-dimensional (3D) recordings of patients while carrying out a standard set of facial expressions, and the processing of these spatial–temporal data in order to facilitate analysis and interpretation.

A new method for precise quantification of the characteristics of facial excursion pre- and post-operative is presented here, with emphasis on smile analysis. This method focuses on the assessment of the trajectories of specific anatomical landmarks during rest and facial expressions. Measures based on the trajectories (position

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over time) of the anatomical landmarks cannot only evaluate abnormalities of spatial nature/topological, but can also assess temporal characteristics.

2. Material and methods

A group of 20 normal patients (without paralysis), 10 men aged between 14 and 50 years and 10 women aged between 18 and 57 years, was used as control group to set up the canonical trajectories for specific anatomical landmarks.

This method is applied and tested in different clinical situations: one normal subject, 3 patients with facial palsy and one patient with severe burns sequels (Table 1).

2.1. Video tracking of anatomical landmarks and the construction of facegrams

In order to reliably capture the dynamics of the smile movements, we developed specialized software capable of simultaneously tracking the position over time of a number of anatomical points. This is accomplished using video recordings of the subject while controlling the process of smiling. Detailed quantifications of the spatial–temporal properties of the muscular dynamics are presented using our newly proposed facegrams. The programming environment MATLAB (R2011a, MathWorks, Natick, Massachusetts, U.S.A.) was used to develop the tracking software, and for computing the facegrams.

2.1.1. Video recordings

In the video recording sessions, the subject is placed with his/her face centered in the camera frame, and with the camera's optical axis perpendicular to the face plane. Using a colour pen, a number of small dots are marked on specific anatomical landmarks. In this work five points were marked: commissures, midpoints and Cupid (Figs. 1 and 2).

The lighting conditions and the pen colour are chosen in order to provide a high contrast between the markers and the subject's skin. During the video recording, the subject is asked to smile, while keeping his/her head still, in a series of 5 stages: rest, contract, hold, relax, rest. This is done over a period of roughly 10 s, with the rest and hold stages lasting 3 s each. It is important to notice that the speeds of the contraction and relaxation stages are not affected by the observer: once the recording session starts, only two voice commands are given – "contract" and "relax". During the recording session, a picture is taken of the subject holding a ruler horizontally in front on his mouth. This picture is later used by the tracking software for space calibration purposes.

Table 1
The facegram was applied and tested in different clinical situations.

Patients/ subjects	Sex	Age	Aetiology	Side	Surgery performed
1[a]	Female	18	–	–	–
2	Female	71	Facial palsy (idiopathic)	Left	Fascia lata suspension (S)
3	Female	37	Facial palsy (acoustic neuroma)	Right	Gracilis transplantation (D)
8	Male	33	Facial palsy (cholesteatoma)	Right	Gracilis transplantation (D)
5	Male	68	Burns (55% TBSA)	Bilateral	–

D: Dynamic procedure; S: Static procedure; TBSA: Total burn surface area.
[a] Standard subject.

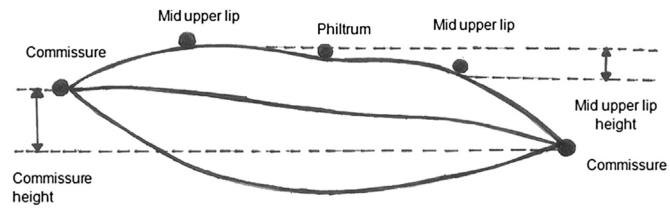

Fig. 1. The selected points (commissures, philtrum, mid upper lip), are placed symmetrical on the vermilion margin; measurements of commissure height and mid upper lip height differences are also performed.

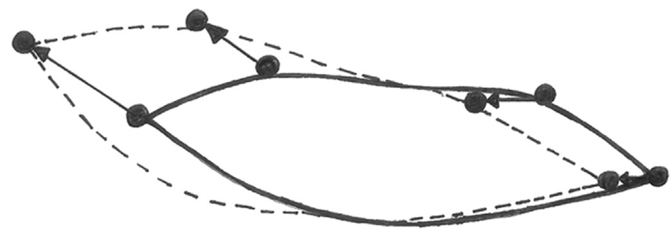

Fig. 2. Movement of the commissures and mid upper lip in a patient with facial paralysis.

2.1.2. Tracking software

Our tracking software is used to convert the video recordings of the subject, acquired under the above mentioned constraints, into lists of (x, y, t) points capturing the movement of the markers associated with the subject's smiling dynamics. The movement is captured in 2D, in the projection of the face's surface into the camera's place. Even using standard, non-expensive HD webcams (50 USD), it is possible to have high resolution in both time (close to 0.03 s, from 30 frames-per-second) and space (close to 0.25 mm). The facial landmark points can have a diameter of 1–2 mm and the spatial precision still be sub-millimetre. This is possible because the tracking algorithm locks on the area of the coloured spot and tracks its centre.

The spatial resolution is therefore largely determined by the resolution of the camera (px/mm) and by the contrast between marker colour and skin colour, not by the area of the spot itself. In high contrast conditions the algorithm is capable of clearly identifying the boundary of the spot/marker and obtaining precise measurements bellow 1 mm.

The tracking system starts by first presenting the initial frame of the video sequence. Here the user is asked to use the mouse to:

1) draw a line setting the face's vertical axis of symmetry and
2) point and click on the coloured dots marking the anatomical landmarks.

The software provides a graphical user interface (GUI) to assist the user in this task. The GUI provides tools such as zooming, and the line axis, together with the marker points, can be edited and visualized over the subject's face. The facial vertical axis is usually defined as the line connecting the mid-glabellar area to the menton. Once line axis and points have been set, an automatic tracking algorithm analyses the video stream, frame-by-frame, extracting the positions of each marker as a function of time. The algorithm uses the "block matching" strategy to track the position of each marker in the sequence of frames. The positions in pixel-space are converted to real-space (in millimeters) using the calibration picture. The scaling factor px/mm is obtained from the length of several centimetres in the ruler. It is therefore possible to estimate the scaling factor with an error which allows sub-millimetre resolution. Despite this we impose a lower bound for this error and