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Motion analysis using 3D motion capture: the case of signer identification in Sign Language

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Up to now, despite the large number of deaf individuals throughout the world using Sign Languages (SLs) to communicate, the vast majority of communication tools only rely on spoken or written languages. Many technological barriers must be tackled in order to provide accessible content in SLs in the same way as for spoken languages. This means developing models of automatic SL processing including automatic SL recognition, translation and in particular, SL generation via virtual signers.

SLs rely on a visual-gestural modality. In that respect, the advances of motion capture (mocap) systems have considerably improved SL generation models, allowing for highly natural and comprehensible movements. It has raised, however, an unexpected problem related to the human ability to identify individuals from their movements. Compared to the auditory domain where a speaker can remain anonymous by modifying specific voice characteristics, little is known about the motion features that characterize a signer's identity. Producing anonymized content with virtual signers is a crucial problem (e.g. for anonymized testimonies on journalistic websites).

Prior research has shown that identity can be extracted from human movements, such as walking or dancing [1], [2], [3], [4] or computational models [5]. What about Sign Language, whose movement features are not only constrained by biomechanical rules, but also by linguistic ones? Visual perception experiments have allowed gaining insights both into the critical motion information necessary for SL comprehension [6], [7], and into the different perceptual strategies of native and non-native signers when processing SL discourses [8]; [9]. However, to the authors' knowledge, there were virtually no attempts neither to assess to which extent human observers actually manage to identify signers from their movements in SL, nor to determine the encoding of identity in the signers' movements.

Our project aimed to (1) gain insights into how the complex structure of SL movements can be modeled; (2) assess whether human perceivers actually manage to identify signers from SL motion; (3) determine the motion features allowing for signer identification and (4) develop computational models to control identity in SL motion generation. On the basis of a 3D mocap corpus in French Sign Language, the present thesis provides five main contributions:

First, we investigated the spectral content of the mocap data of spontaneous LSF. Across six different signers, Power Spectral Density estimation and residual analysis of the mocap data revealed that SL motion can be limited to a 0–12-Hz bandwidth, which is substantially wider than state-of-the-art estimates on isolated signs. These results suggest that SL motion involves higher frequencies in real-life conditions.

In addition to these time-frequency analyses, we used Principal Component Analysis (PCA) to decompose SL motion into elementary movements called principal movements (PMs). Common PMs were extracted from the whole dataset containing all six signers, while individual PMs were extracted separately from the data of individual signers. Although the data were not synchronized in time across signers and examples, individual and common PMs explained the same amount of variance in the movements and were highly similar. These results suggest that SL may have a common structure that can be decomposed into simpler patterns using PCA.

We then investigated person identification from SL movements. Using Point-Light Displays, a visual perception study revealed that participants managed to identify familiar signers above chance level. Combined with computational analyses of both the mocap data and the participants responses, behavioral results revealed that mocap data contain sufficient information to identify signers, beyond simple cues related to morphology.

We then trained a machine learning model to determine the motion features allowing for the automatic identification of signers. A PCA was applied to time-averaged statistics of the mocap data. A linear classifier then managed to identify the signers from a reduced set of principal components. The performance of the model was not affected when information about size and shape of the signers were normalized. Posture normalization decreased the performance of the model, which nevertheless remained over five times superior to chance level. These findings demonstrate that a signer's identity can be characterized by specific statistics of kinematic features, beyond information related to size, shape and posture.

Finally, a synthesis algorithm is proposed in order to re-synthesize natural SL movements for which the identity of the signer is controlled while semantic information is kept intact. To do so, the identity-specific feature statistics extracted by the above machine learning model are manipulated. For instance, the impact of identity-specific features of the signer can be reduced (i.e. anonymization), as well as the importance of identity-specific features of another signer can be increased (i.e. identity conversion).

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