Experiences Collecting Motion Capture Data on Continuous Signing

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Abstract

This paper describes some of the experiences the authors have had collecting continuous motion capture data on Finnish Sign Language in the motion capture laboratory of the Department of Music at the University of Jyväskylä, Finland. Monologue and dialogue data have been recorded with an eight-camera optical motion capture system by tracking, at a frame rate of 120 Hz, the three-dimensional locations of small ball-shaped reflective markers attached to the signer's hands, arms, head, and torso. The main question from the point of view of data recording concerns marker placement, while the main themes discussed concerning data processing include gap-filling (i.e. the process of interpolating the information of missing frames on the basis of surrounding frames) and the importing of data into ELAN for subsequent segmentation (e.g. into signs and sentences). The paper will also demonstrate how the authors have analyzed the continuous motion capture data from the kinematic perspective.

Keywords: motion capture, mocap, sign language, continuous signing, kinematic analysis

1. Introduction

The term *motion capture* (mocap) refers to the process in which a person's bodily movements are recorded and transformed into a digital format for further processing and analysis. The recording is normally done with infrared cameras that track the three-dimensional locations of reflective markers attached to the different parts of the person's body. The recording results in a numerical coordinate matrix that can be used as a source data for analysing the movements of the body and its parts from a kinematic perspective. Alternatively, the results of the recording can be used to build animated models of the moving person.

In sign language research, mocap data is generally considered to be the most accurate type of data available for signal-wise oriented, i.e. phonetic research. However, limitations in the availability and accessibility of the necessary technology have probably caused the number of studies taking advantage of it to remain relatively low. Examples of early studies exploiting mocap data are Wilbur (1990) and Wilcox (1992), who investigated stressed sign production and the kinematics of fingerspelling, respectively. More recent examples include Tyrone et al. (2010) and Duarte and Gibet (2010a). Of these, the former focused on variation in the hands' movements towards and away from the body, while the latter investigated variation in the kinematic characteristics of intersign transitions.

The data of most mocap studies into sign language have consisted of only relatively small sets of *isolated* expressions such as single signs (Wilbur, 1990), short fingerspelled sequences (Wilcox, 1992), or (carrier) phrases (Tyrone et al., 2010). The collection and exploitation of *continuous* mocap data, i.e. durationally longer discourse-type data, has been marginal (cf. Duarte & Gibet, 2010a). This is probably due to the fact that recording, processing, and analysing such data is extremely time consuming. However, such an endeavour is often worth the effort, mainly because of the inherent multifunctionality of such data. Continuous mocap data can be used not only in traditional sign-related phonetic studies (for an overview, see Duarte & Gibet 2010b) but, when accompanied with video, also as (supporting) corpora in studies that investigate sign language from various other, e.g. syntactic and discourse, perspectives.

The aim of this paper is to share some of the experiences the authors have had collecting continuous mocap data on Finnish Sign Language (FinSL) for the purpose of general phonetic and especially syntactic analysis. Our focus will be on issues that we consider to be crucial for the success of this type of mocap data collection, but which at the same time are also important for mocap-related work on sign languages in general. The topics covered include the issue of marker placement, the process of gap-filling, and the importation of mocap data into ELAN with video (Section 2).[1] We will also demonstrate how we performed kinematic analysis on our continuous mocap data (Section 3).

2. Collecting Continuous Mocap Data on Finnish Sign Language

We have been involved in collecting continuous mocap data on FinSL since the autumn of 2010. All the recordings have taken place in the motion capture laboratory of the Department of Music at the University of Jyväskylä, Finland. The laboratory hosts an eight-camera optical motion capture system (Qualisys ProReflex MCU120). The cameras have recorded the

[1] http://www.lat-mpi.eu/tools/elan/

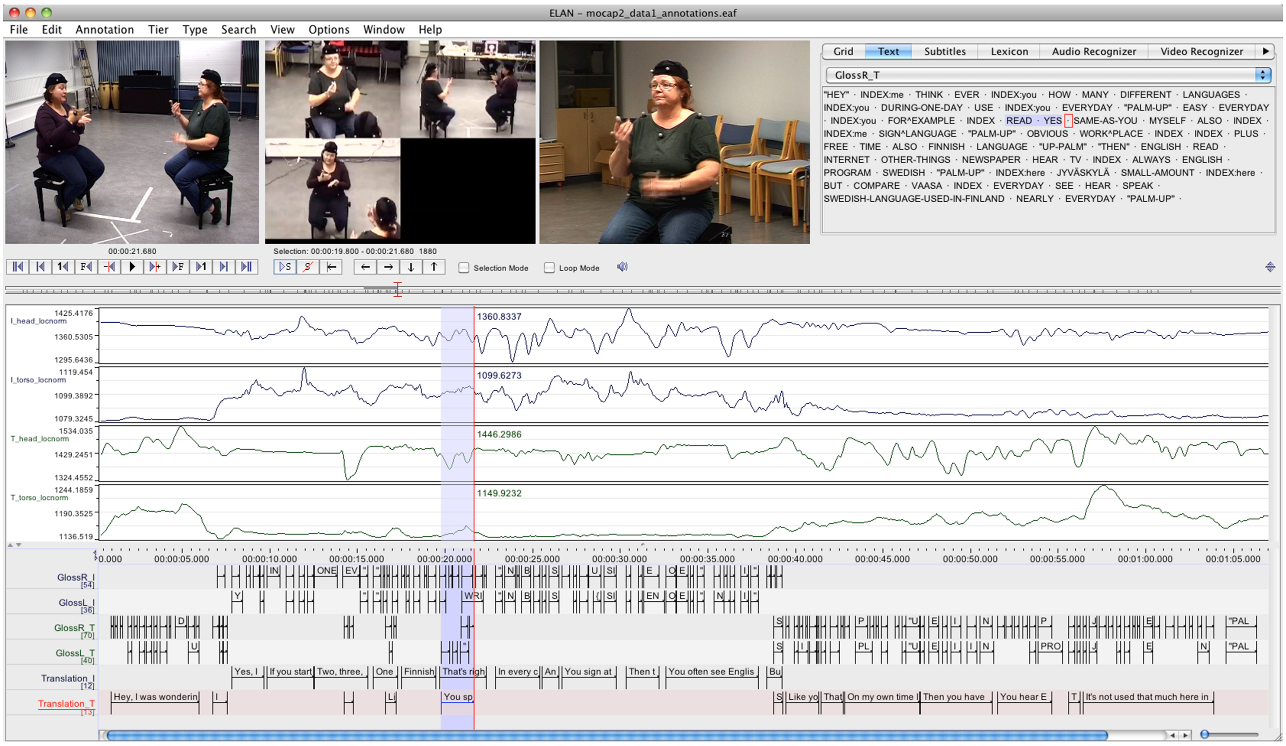

Figure 1: ELAN screenshot showing annotated video and motion capture data (lengths of location vectors describing the movement of the head and torso of both signers) recorded in a dialogue situation.

motion of the signer by tracking the three-dimensional locations of small ball-shaped reflective markers attached to the signer's hands, arms, head, and torso (see Section 2.1). The frame rate of the cameras has been 120 Hz, which is comparable to the frame rate of 100 Hz used in most modern sign language-related mocap work (e.g. Duarte & Gibet, 2010ab; Tyrone et al., 2010).

In addition to the mocap cameras, the laboratory also has a set of digital video cameras that are synchronizable with the motion capture system. In the data collection, the video cameras have recorded the signer from different angles and provided crucial supporting material for the later process of segmenting the quantitative mocap data into identifiable and processable chunks (e.g. into signs and sentences). In our work – as also in the work of Duarte & Gibet (2010ab) – the segmentation process has been done in ELAN, into which both the mocap data and the video data have been imported (see Figure 1). In general, ELAN has been a valuable tool for combining and controlling data obtained from conceptually different sources, and it also includes functions that allow the researcher to do simple numerical analyses with the data (Crasborn & Sloetjes, 2008). However, in our work, most of the actual analysis of the data has been done in Matlab using the *MoCap Toolbox* developed by Toiviainen & Burger (2011).[2]

In the following, we discuss some of the key issues in the data collection process. The discussion is carried out within two main themes that correspond to the two main phases of mocap data gathering: data recording (2.1) and data processing (2.2). The discussion is illustrated with examples from the continuous mocap data collected both in monologue and dialogue situations.

2.1 Data Recording

One of the most important questions in mocap data recording concerns marker positions: where to attach the reflective markers, and why? The issue is important because the location of markers affects their visibility in the system: covered markers are not recorded. Furthermore, markers that are placed inappropriately might make it difficult for the signer to properly articulate signs. Marker positions are also important from the point of view of potential post-processing steps such as transforming the three-dimensional marker data into joint or segment representations (Toiviainen & Burger, 2011: 43, 46). Such processes are needed if one wishes to investigate, for example, the motion of the centroid of a certain joint or the kinetic energy of body parts.

Figure 2 shows the basic marker setup that we have used in our recordings. The total number of markers in the setup is twenty. The head has four markers at the level of the forehead; each arm and hand have seven markers in the main joint positions (the shoulder, elbow, ulnar and radial wrist joint, the most proximal joint of the index finger, and the tips of the index finger and thumb); and the upper torso has two markers, one in the middle of the chest (clavicle) and one on the back (C7).

[2] http://www.jyu.fi/music/coe/materials/mocaptoolbox/

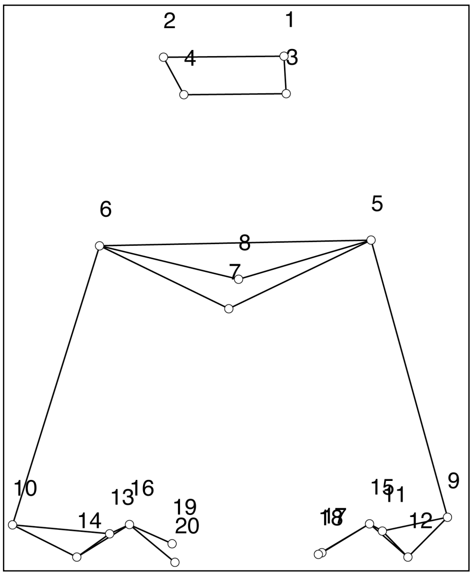

Figure 2: The basic marker setup in our mocap data showing basic marker connections and marker numbers.

The marker positions in our basic setup (Figure 2) have been decided so that the markers are maximally visible and identifiable to the system (our signers sit during the recording), and maximally processable (e.g. in data transformations), and so that they capture the main global movements of the hands, arms, upper torso, and head. The various local rotational movements of the wrist and index finger of both hands are also captured by the setup. The index finger has been preferred over other fingers because it is the finger that is most responsible for controlling and maintaining the rhythm and speed of signing (Ojala, 2011). The tip of the index finger has also been the reference point in other mocap-related studies (e.g. Wilbur, 1990; Wilcox, 1992).

We have deliberately wanted to keep the number of markers attached to the hand and fingers low because markers attached to these locations can easily impede the proper articulation of signs. This negative effect has been documented even with our present setup, which includes only three markers on the hand and fingers. Our signers have reported that especially the articulation of signs involving contact of the index finger with the body has occasionally been unnatural.

In comparison with other modern mocap studies, the total number of markers in our basic setup is relatively low: Tyrone et al. (2010) used thirty markers (7 on each arm, 7 on the head, and 9 on the torso) and Duarte & Gibet (2010b) – whose additional goal is to use the data to create animated signing figures, avatars – employed ninety-eight markers (43 facial markers, 43 body markers, and 12 hand markers, with 6 on each hand). The main difference between our basic setup and these other setups lies in the number of torso and head markers. In the recording of our dialogue data, we have experimented with adding more markers precisely in these areas. An example of an extended marker setup in which the number of markers per signer is thirty-one is illustrated in Figure 3.

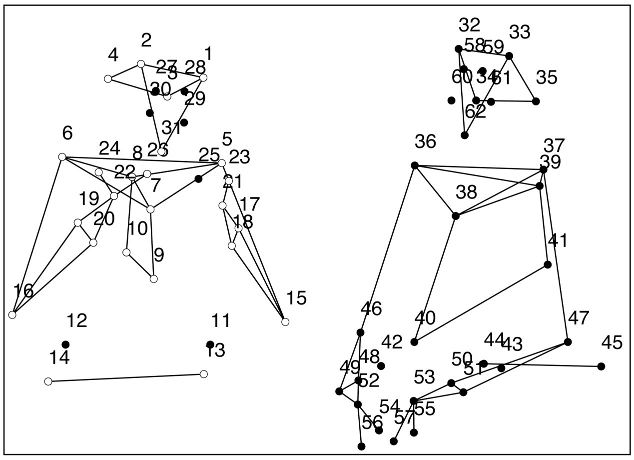

Figure 3: Our extended marker setup for dialogue (see Figure 1) showing the most important marker connections and marker numbers.

In this extended setup (Figure 3), the number of markers has been increased by five on the facial area (both brows, both cheeks, and the chin) and by six on the lower torso area (abdomen, T10, and altogether 4 hip markers), the rest of the marker locations corresponding to those in the basic setup. The main advantage of this extended setup is that, while keeping the data comparable with those recorded with the basic setup, it also captures the rigid lower torso movements. Also the movements of the head are now captured in more detail.

However, in general, the capturing of facial movements with the setup presented in Figure 3 proved not to be very succesful, as the facial markers did not remain visible to the system all the time. This was probably caused by the relatively small size of the reflective sticker tapes that we had to use on the face in place of the ball-shaped markers; the markers were easily covered by the hands articulating on the facial area. Also the markers attached to the lower torso area were not always picked up by the system. We suspect that this was caused by the fact that the signers were sitting during the recording and occasionally their shirts covered especially the hip markers. In the future, the obstruction of markers can be avoided by asking the signers to wear "mocap jackets" that are made from stiff fabric and thus keep the marker positions maximally visible.

In general, our experience is that a higher number of markers does not automatically produce better data. However, the choice of the number of markers is ultimately dictated by the specific goals of the mocap recording (cf. animation in Duarte & Gibet, 2010b). For the purpose of collecting continuous mocap data on FinSL for general kinematic use, we have found that our basic marker setup (Figure 2) supplemented by abdomen

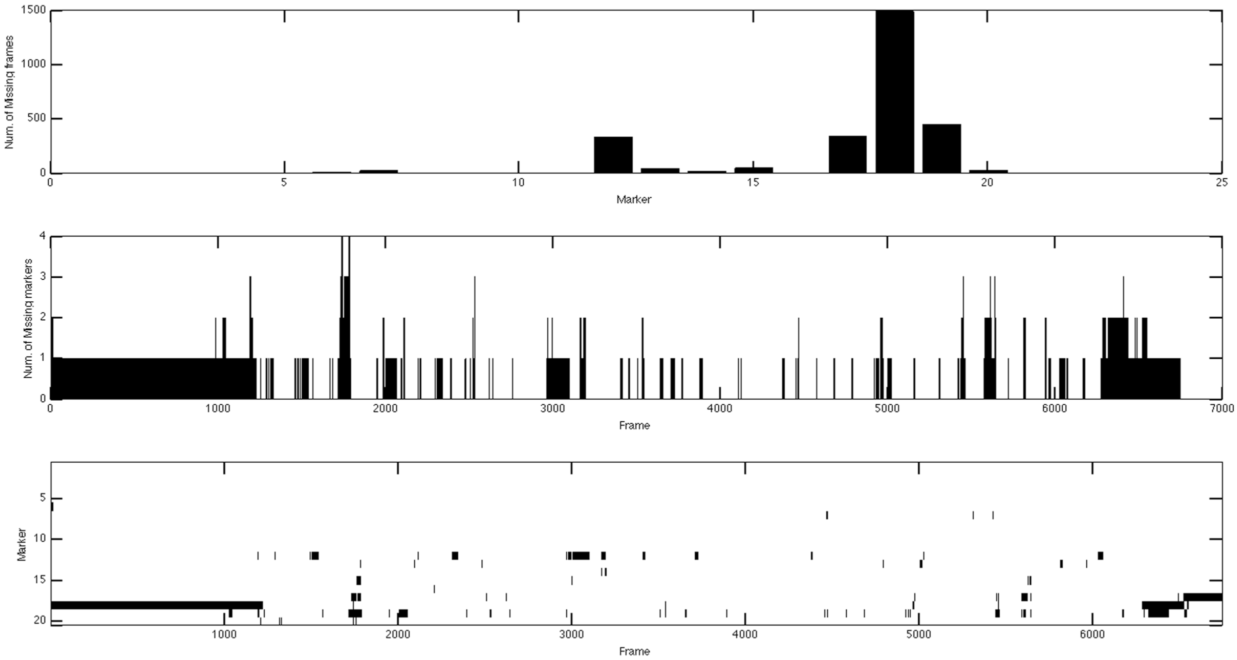

Figure 4: Three diagrams showing the original gaps in the 50 second-long monologue data. The top diagram illustrates the number of missing frames per marker; the middle diagram illustrates the number of missing markers per frame; and the bottom diagram illustrates for which frame(s) which markers were not recorded.

and T10 markers (see Figure 3) is sufficient, both from the point of view of the movements that it captures and the processing it allows.

2.2 Processing of the Data

2.2.1. Gap-filling

After the mocap data has been recorded, there are several essential steps that one has to take with it in order to make it into an analysable format. One important step is the process of gap-filling that takes place after the marker locations in the data have been assigned distinctive identities (i.e. the markers have been labelled). Gap-filling means searching for the empty frames that almost always occur during the recording and interpolating the missing data on the basis of the information in the surrounding frames. Normally this is a fairly automatic and reliable operation but it may also produce false results (e.g. when the gap is relatively long) which the researcher needs to take into account when assessing the validity of the results.

Figure 4 shows the original gaps in the approximately 50 second-long monologue data used in Section 3 to demonstrate how continuous mocap data in general can be used in kinematic analyses. The diagrams in the figure are the plots created from the output of the function *mcfillgaps* of the Matlab-based *MoCap Toolbox* used in the analysis of the data. The diagrams show that there have been slight problems in the visibility of markers attached to both thumbs (markers number 17 and 19 in the top diagram) and the one attached to the ulnar side of the wrist of the nondominant hand (number 12). More serious visibility problems have occurred with the nondominant hand index finger marker (number 18), especially immediately after the beginning of the recording and at the end of the recording (see the bottom diagram); at the beginning the first three frames were recorded (this cannot be seen from the bottom diagram of Figure 4 because of the scaling) but then there is a gap of about 1200 frames. The gap resulted from the fact that the hands and fingers were turned in such a way that the system could not see the markers.

The gap-filling algorithm of the *mcgapfill* function is able to successfully interpolate the missing data for most gaps shown in Figure 4 because of their relatively short duration. However, the longer duration of the gap of the nondominant hand index finger marker (18) at the beginning of the data cannot be handled properly by the default use of the gap-filling algorithm. This is demonstrated in Figure 5, which shows the locations and connections of the markers in frame number 1132 of the data. This frame occurs a few moments before the end (frame 1209) of the long initial gap of marker 18, i.e. just before the moment the nondominant hand starts to move up from the resting position towards the place of articulation of the FinSL sign WINTER. The linear interpolation of the gap between frames 3 and 1209 results in a slow and regular rising of the nondominant hand index finger marker to reach the position in the upper torso area when the marker was detected again. In order to overcome this problem, we used the *maxfill* parameter of the *mcfillgaps* function of the *MoCap Toolbox*. The parameter specifies the maximal length of gaps to be filled; longer gaps are not processed (see Toiviainen & Burger, 2011: 76). A more accurate though more time consuming way would be not to fill such gaps linearly, but to take the surrounding markers into account; in this case, the nondominant hand index finger marker would only start moving when the other hand/arm markers move and adapt its speed accordingly.

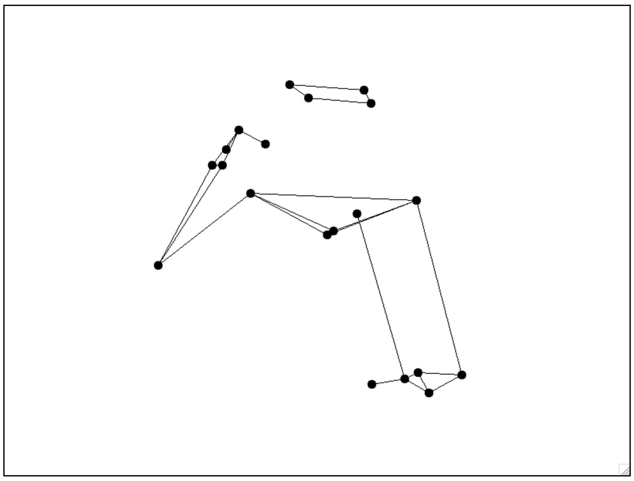

Figure 5: Unsuccessful gap-filling process.

As the gap-filling process alters the data and this can lead to undesired outcomes, it is sometimes tempting not to apply it to the data at all. However, in order to make continuous mocap data maximally analysable from the kinematic perspective, some gap-filling is normally required. The important thing is to check the outcome of the gap-filling process. The most convenient way that we have found to do this has been to create an animated stick figure model of the signer(s) on the basis of the processed data (cf. Figures 2, 3, and 5). These types of animations are easily constructed with the functions of the *MoCap Toolbox*. The animations also have other advantages. For example, our experience is that they are the easiest way to see whether marker identities are assigned correctly and markers are tracked properly, even before the gap-filling procedure. Particularly from the perspective of sign language-related mocap work, stick figure animations are also the best way to ensure that the recorded numerical data actually represents activity that is identifiable as signing, i.e. makes sense linguistically.

2.2.2. Importing Mocap Data into ELAN

In order to make the continuous mocap data usable for linguistic analyses, it needs to be imported with the video material into a data management program in which it can be segmented into more processable chunks. In our work, we have managed the data in ELAN. The process we have used in importing the data into ELAN involves several steps. As there are no standard guidelines for this type of work, we will now describe these steps.

The first step is the cropping of the data. The mocap recording with our system results in a three-dimensional numerical coordinate matrix in .tsv format. With our basic setup of twenty markers, this matrix consists of sixty columns, i.e. three for each recorded marker (x, y, and z dimensions). However, ELAN (ver. 4.1.2) is able to process additional data files that include a maximum of twenty columns of numerical information (and of these at least one column must include timecodes). Consequently, in order to make the mocap data importable into ELAN, the data first needs to be cropped, i.e. unwanted or otherwise redundant marker columns need to be removed from the matrix.

In our work, we did the cropping by opening the original (gap-filled) matrix in Matlab and copy-pasting the desired columns of marker coordinates onto an empty Excel spreadsheet. Before the columns are copied into Excel, their information can be further processed in Matlab with the *MoCap Toolbox*. An example of some simple processing that we have normally done for the data at this point is the calculation of velocity and acceleration vectors and their Euclidean Norms (i.e. magnitudes, or lengths) for the marker location data. When all the relevant columns are copied onto the Excel sheet, one gets a reduced yet also augmented version of the original data that can contain information, for example, on the three-dimensional locations of the tip of index finger and chest (C7) markers (3+3 columns) as well as on the velocity and acceleration of these markers in all three dimensions (2x(3+3) columns).

The second step in the process of importing continuous mocap data into ELAN is the generation and addition of timecodes and frame numbers onto the Excel sheet containing the cropped (and usually augmented) data. In order for any additional data file to be processable in ELAN, it must include the timecode information in one column. Such information – or frame number information – is not automatically exported by our mocap system and we have used a specific JavaScript code to generate it. Once the incremental timecode and frame number information is generated for all the frames of the data, it is added into the first two columns of the Excel sheet. Note that because timecodes and frame numbers require two columns on the Excel sheet, the maximum number of mocap data columns that can be copied onto the sheet from Matlab is eighteen.

After the Excel sheet containing timecodes, frame numbers and the relevant mocap data is completed, it is saved as a file in .csv format. This is the format ELAN uses to process additional data files.

The third and final step in getting the mocap data into ELAN is the actual data import process. First, the video recorded with the mocap data is imported; the video has been synchronised with the mocap data by our mocap recording system but we have found that minor editing (cropping) work with the video is still often required to make its length correspond to that of the mocap data. The primary video used in ELAN is added through the normal process of creating a new ELAN annotation file. Additional videos (as in Figure 1) may be imported through ELAN's *Linked Files* function (the Linked Media Files tab), found in the *Edit* menu.

The .csv data file created in Excel is also imported into ELAN through the *Linked Files* function (the Linked Secondary Files tab). Note that the number of files to be added is not limited to one. The twenty-column limitation of one file is thus compensated for here with the possibility of working with several twenty-column .csv files.

After the addition of data file(s), the columns containing the numerical information in the file(s) need to be configured for ELAN. This is done by control clicking anywhere in ELAN's Timeseries Viewer, which contains the (still empty) trackpanel(s) and, from the menu that appears, choosing the *Configure Tracks* option. This opens up a dialogue box that displays the maximum of twenty data columns included in the .csv file and several options of how they can be configured to be shown as tracks (i.e. linegraphs) in the trackpanels of ELAN's main screen. In addition to specifying the data in columns, it is crucial to define the timecode column that ELAN uses to synchronise the data with video(s) and annotations.

An example of the end result of the import procedure is presented in Figure 1. The figure also shows how the data has been segmented into signs by following the annotation layout of the "Corpus NGT" (Crasborn & Zwitserlood, 2008). The completed annotation makes it possible to use ELAN's *Extract Data* function (accessible through control clicking the Timeseries Viewer) to automatically generate annotation cells corresponding to the durations of signs and to display the initial and final frame number of each sign in these cells on the basis of the information in the underlying .csv file. This frame number information is needed for successful analysis of specific signs and their sequences (e.g. sentences) in Matlab with the *MoCap Toolbox*.

3. Analysing the Data

Continuous mocap data can be used for a variety of purposes. The most straightforward use of the data is to exploit it to support the annotation of sign language corpora. The information concerning the motion of the hands visualised in ELAN has undeniable value for the segmentation of continuous signing into signs and other linguistic units. The changes in the direction of the movement of the hands and other articulators such as the head and torso, which often mark linguistic boundaries, can be hard to notice by looking only at the video, but they are easily detected by looking at the graphs representing the changes in the three-dimensional locations of the markers.

However, the real value of the continuous mocap data lies in its use for the kinematic analysis of signing and the linguistic units contained in it (e.g. signs and sentences). In the following, we give examples of these types of analyses with one set of our monologue data. The data comprises a story lasting about 50 seconds in FinSL describing a wintertime cycling incident near Jyväskylä University. The data has been recorded with our basic marker setup with twenty markers.

3.1 Analyses Based on Location Data

In our ongoing work, we have used the three-dimensional marker location data to calculate the cumulative distances travelled by different markers during the production of different FinSL sentences (with the function *mccumdist* in the *MoCap Toolbox*; the focusing on these types of specific sequences in the continuous data has been enabled by the frame number information extracted in ELAN, see 2.2.2). Figure 6 illustrates the result of such a calculation for one FinSL sentence. The markers involved in the calculation were the dominant hand index finger tip marker and the front right head marker.

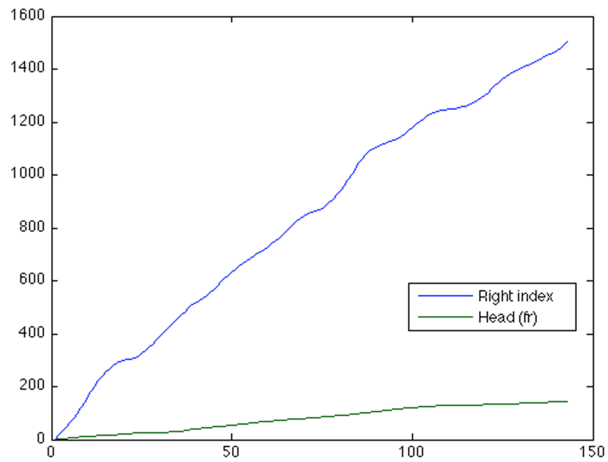

Figure 6: The cumulative distance travelled by the dominant hand (upper line in blue) and the head (lower line in green) in FinSL sentence ME HAVE-TO GO-TO UNIVERSITY 'I had to go to the university'. The distance is measured in millimeters per frame.

The diagram in Figure 6 shows that in the production of this particular sentence the tip of the index finger travelled a distance of about 1.5 meters. In the same amount of time, the distance travelled by the head was only about 0.2 meters. The difference is predictive for declarative FinSL sentences in general.

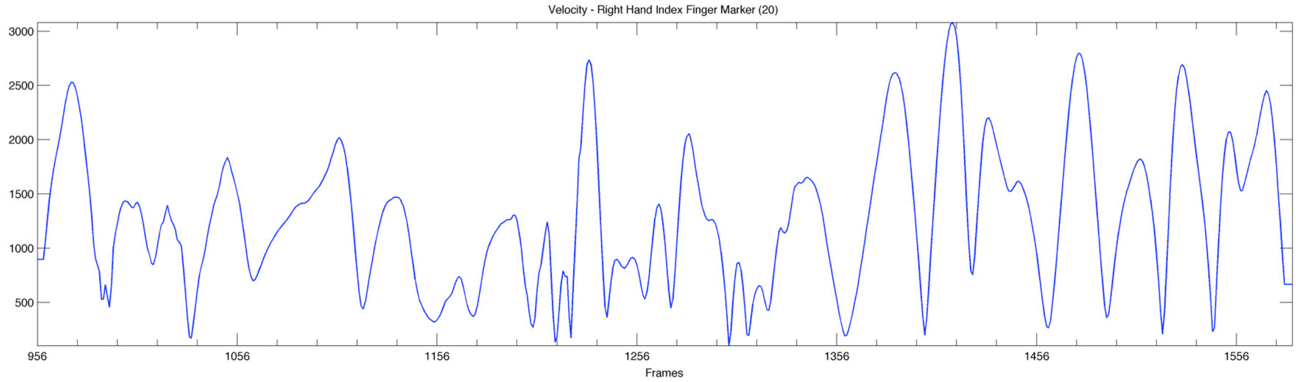

Figure 7: Velocity magnitude plot for the sequence of the first nine signs in the present monologue data. Velocity magnitude is measured in meters per second.

More generally, we have also used the marker location data to study correlations between movements produced with different articulators. The correlations have been calculated on the basis of both the three-dimensional location data and the Norm data, representing the variation in the length of the location vectors of markers (cf. Figure 1). Table 1 summarises some results of this work for Norm data on the monologue used in the present study. The articulators investigated are the dominant hand (operationalized as the centroid of the dominant hand ulnar and radial wrist marker), the head (the centroid of head markers), and the upper torso (the centroid of clavicle and C7 marker).

Articulators	*R*	*Interpretation*
wrist-head	0.217	weak
wrist-torso	0.520	strong
head-torso	0.764	very strong

Table 1: Correlations in the motion of three articulators in the monologue Norm data.

The results show that the motion of the hand follows the motion of the upper torso (correlation co-efficient=0.520) but not that of the head (0.217). The motion of the head closely follows the motion of the upper torso (0.764). The interplay of the articulators is largely explained by the anatomy and physiology of the human body.

3.2 Analyses of Velocity and Acceleration

We have also used our continuous mocap data to investigate the velocity and acceleration characteristics of signs and sentences. For this purpose, we have applied especially the Euclidean Norms of velocity and acceleration vectors calculated on the basis of the three-dimensional marker data (with *MoCap Toolbox* functions *mctimeder* and *mcnorm*). Some results of this investigation are shown in Figure 7, which presents the magnitude of the velocity (i.e. speed) of the index finger tip marker as a function of time during the first nine signs of the present data.

Figure 7 shows that the speed of the tip of the dominant hand index finger marker varies considerably in continuous signing. In general, moments of slowest speed in the plot are identified fairly accurately with the borders of sign strokes (Kita et al., 1998). The moments of highest speed, on the other hand, associate either with the middle phases of strokes or with transitions.

3.3 Analysis of Rhythm

Examples of more complex analyses with the continuous mocap data include analyses of the inherent rhythm of the motion of different articulators. In our work, we have focused especially on the rhythm of head movements in FinSL sentences. In our investigation of this phenomenon, we have defined the notion of rhythm as regularity and predictability in motion. From this perspective, we have used autocorrelation to study the periodicity and aperiodicity of head movements (with the *mcperiod* function in the *MoCap Toolbox*). The three diagrams in Figure 8 show some of the results of this investigation.

In Figure 8, the diagram of two consecutive transitive clauses illustrates how in these types of clauses the head normally moves from side to side in a fairly periodic manner with relatively low amplitude. This class of side-to-side head movements contrasts with those typically found in FinSL topic-comment structures (Jantunen, 2008) and in negative expressions. In topic-comment structures, the head movement is aperiodic, the break in the regularity of rhythm being caused by the tendency to keep the topic prosodically detached from the following comment. In negative expressions the movement of the head is again periodic. However, in comparison to prototypical transitive clauses, the amplitude of the side-to-side head movements in negative expressions is higher.

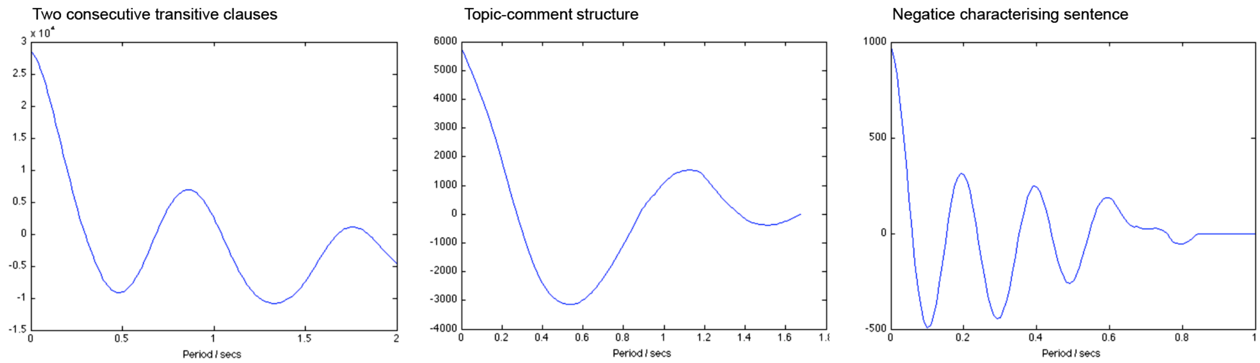

Figure 8: Descriptors of the autocorrelation function illustrating the periodicity of sideways head movement in three types of prototypical FinSL sentences.

4. Conclusion

This paper has described our experiences in collecting continuous mocap data on FinSL. The description has focused on several key issues in mocap data recording (marker placement), processing (gap-filling, importing data into ELAN) and analysis (the kinematic analysis of signs and sentences) and shown that mocap data collection is a complex process involving several steps and requiring expertise in different scientific fields. In the future, we would like to see more researchers collect more continuous mocap data and use it in sign language studies on all aspects of linguistics. Our own plans for the future include continuing both our data collection and the analyses demonstrated in the paper. We will also examine the possibility of adding our continuous mocap data to the FinSL corpus, preparations for which are currently being made.

5. Acknowledgements

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