COMPARISON OF THE AUTOMATIC MARKER-LESS BODY SEGMENTS TRACKING AND THE TRADITIONAL MARKER-BASED APPROACH

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Abstract: In this paper, results of a novel technique for the evaluation and analysis of human gait based on the tracking of five body segments in sagittal plane are presented. The accuracy and possibility of application of new approach has been investigated. Comparison results of the gait data obtained by marker-less and traditional marker-based approach are given and they showed that the marker-less tracking can produce reliable data for the gait analysis.

Introduction

Today, three principal approaches of the motion capture technologies are dominantly used; electromechanical, electro-magnetic and optical tracking of signals. Optical tracking systems are perhaps the most popular because they present the least restrictive approach that uses one, two or more cameras used to acquire 2D/3D position data of the markers attached to the chosen characteristic locations of the observed person [1]. The cameras are widely available and generally inexpensive and the computer vision algorithms for the determination of the marker locations in the acquired images are well–known, reliable and fast enough for the real time data processing.

Although the marker-based approach is the least restrictive out of the above mentioned approaches, it is not completely without restrictions. For example, markers have to be accurately positioned, they can also be occluded and their positioning can be time consuming. The natural answer to these problems is the attempt to apply marker-less approach. As a consequence, intensive research of the marker-less tracking techniques has been conducted lately. Because the body tracking techniques can be implemented in various areas of applications such as sports [10], film [6], military, human-computer interface, robotics [9], medicine [5] etc., focus of the investigation varies. Different algorithms, procedures ad techniques have been used for pose estimation out of single image [4] or sequence of dynamic images [7][8].

Our focus will be on investigating the possibility of using marker-less tracking in clinical application which implies narrowing the scope of the research. The contribution of the paper will be in presenting the comparison of the gait results obtained by the procedure developed by the authors and the results obtained by the traditional marker–based approach. This way, possible critical issues could be outlined. The paper is organized as follows. In the Materials and Methods section is presented a brief description of the marker-less tracking technique developed and used as the object of our interest. Further, in the same section, chosen comparison procedure is explained in detail. Results of the applied procedure are given in the Results section and discussed in the following section. A conclusion based on the evaluation of the obtained results and possible further research and improvement of the used tracking technique, is given in the last section.

Materials and Methods

For the presented case example, gait video data acquired from only one camera was used because the focus of our investigation was on the sagittal plane movements. Five markers were attached to the right side of the subject's body: shoulder, hip, knee, ankle and fifth metatarsal. These characteristic points were sufficient for the purpose of technique evaluation and the calculation of angles of interest in the gait analysis.

Using Matlab software package and Borland C++ Builder application development software, windows-based computer programs were developed for the traditional marker–based and marker–less tracking. Windows program for the extraction of marker positions has two working modes: automatic and manual. In order to avoid possible marker recognition errors due to scene lighting, marker occlusion or some other problems, manual extraction of the marker coordinates was done. This is significantly slower mode, but for the evaluation purposes, the speed of the data extraction was not the priority. After the marker coordinates extraction, characteristic angles used for the sagittal gait analysis were calculated [3] along with angular velocities and accelerations.

Extensive use of existing and newly developed computer vision algorithms was included in the tracking technique developed for the obtaining needed gait data without use of the markers. The novel technique is based on tracking of five body parts: head, trunk, upper-leg, lower-leg and foot. Recognition of these body parts in each image of the gait video sequence made possible the reconstruction of body pose and the calculation of standard angles used in clinical gait analysis.

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Recognition and processing of the sequence has two main phases: initialization phase and tracking phase. Processing of the first image of the sequence presenting heel contact phase of the gait cycle is done in the initialization phase. All the other images of the sequence are processed in the tracking phase. Tracking procedure introduces so called chain winner algorithm used for the recognition of the heel-fifth metatarsal line. The optimization is done by narrowing the search to the ending segments of the body – head and foot. The pose reconstruction is done by connecting the body segments with known shapes and sizes (obtained in the initialization phase) knowing the starting (head) and ending (heel-fifth metatarsal line) points. Of course, this is only the simplified explanation of the applied technique that also uses cross-correlation algorithms, anthropometric data, heuristic rules etc.

Figure 1: Typical frame of walking sequence after marker removal.

In order to compare both sets of gait cycle data – one obtained by traditional marker extraction and other by marker-less tracking, series of recorded sequences presenting one gait cycle were used. Original sequences contained the subject with the markers attached. After several sets of the results obtained by processing gait sequences of the person with markers attached to the body, the first set of test data was obtained. After that, the same sequences recorded in computer avi format, were edited and the markers from the images were manually removed (Figure 1). After applying procedures for the marker-less tracking, another set of data used for the comparison with the first one was formed.

The comparison procedure is presented in figure 2. It should be noted that the comparison module in the figure 2 also includes data filtering. This has been done in order to remove data acquisition noise. Fourier filtering was implemented and all the frequencies above seventh harmonic (approx. above 7 Hz) were removed. These values were used because the investigations regarding the highest possible speeds of the particular body segments suggested that cut-off frequency should be around 7 Hz [2].

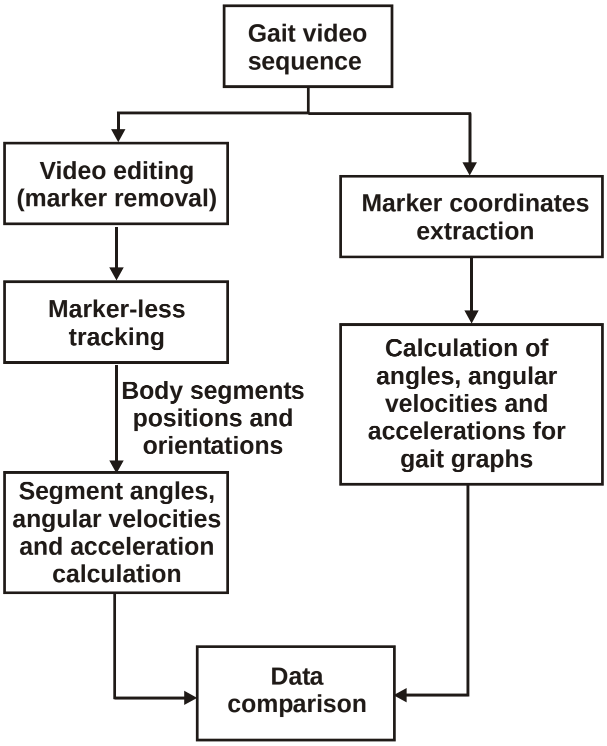

Figure 2: Comparison procedure

Results

The comparison of the hip and knee angle values obtained by marker–based and marker–less approach using so called virtual markers are given in figures 3 and 4. Graphs of the hip and knee angle velocities are presented in figures 5 and 6.

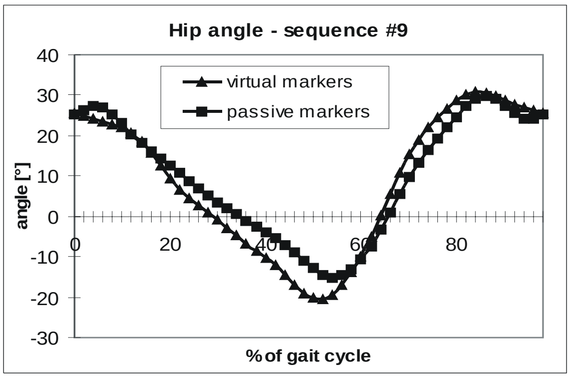

Figure 3: Hip angle calculated out of traditional and marker–less images.

Because the velocities are obtained by numerical derivations of angle values, second derivations i.e. obtained angular velocities graphs couldn't produce any unexpected deviations regarding the correlation of both data series. For this reason, accelerations are not

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presented here because accelerations correlations are also directly dependable on the angle correlations.

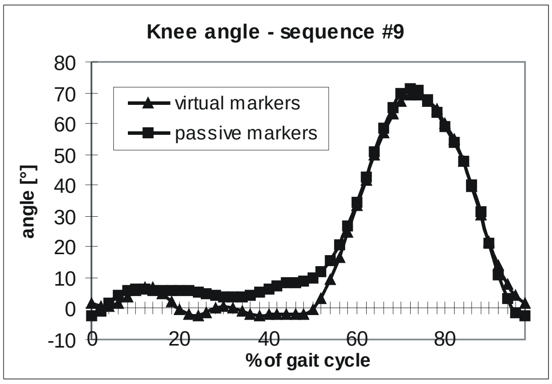

Figure 4: Knee angle calculated out of traditional and marker–less images.

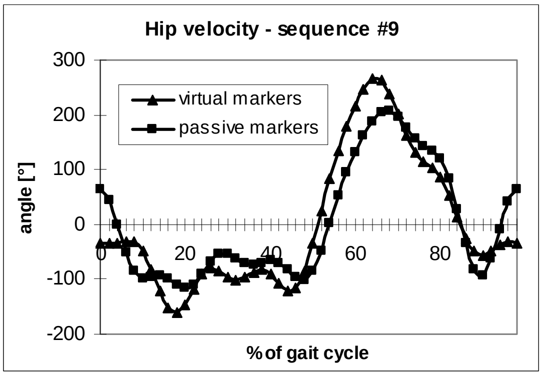

Figure 5: Hip angular velocity calculated out of traditional and marker–less images.

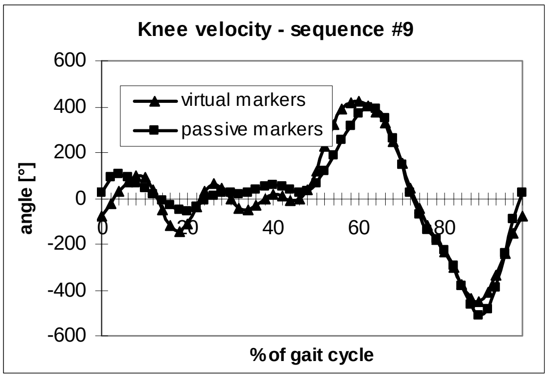

Figure 6: Knee angular velocity calculated out of traditional and marker–less images.

Unfortunately, marker removal (image editing) significantly degraded the foot edges needed for the calculation of ankle angle in marker-free images so the data couldn't be adequately compared. Ankle angle graphs of the gait sequences originally recorded without markers attached to the subject's body, showed expected angle values for the normal gait (Figure 7).

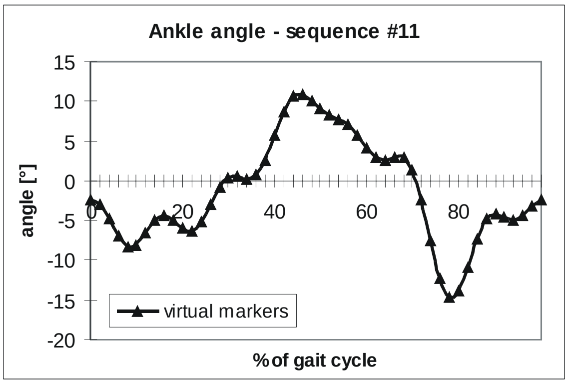

Figure 7: Ankle angle obtained by marker-less tracking

Maximal angular difference, standard deviation, average difference and calculated correlation coefficient for the two angles are presented in Table 1.

Table 1: Difference between the calculated angles obtained by data obtained with and without markers

Angle	Hip [°]	Knee [°]
max.difference	9.58	13.38
standard dev.	4.44	4.66
average diff.	-1.61	-3.75
correlation coeff.	0.980	0.984

Discussion

As it can be seen from the obtained results, the largest differences for hip and knee angle were under 10° and 14° respectively. Correlation coefficients calculated for data measurements with and without markers confirmed the visual impression and showed that graph shapes were almost identical. This is quite satisfactory because in clinical gait analysis, correlation of graphs representing average normal gait and recorded case has higher importance than actual deviation expressed in degrees. Problems with accurate marker positioning and marker movements due to skin-bone interaction results in possible marker graph offset errors. Of course, this is not an issue if the markers weren't used at all. Tolerated standard deviations for the gait analysis are, for some angles and phases of gait cycle above 15°.

Knee and hip angle marker-less results showed the highest discrepancy with the results obtained with marker tracking for the mid stance phase of the gait cycle. Differences of the results for this phase were registered even by other researchers [4].

It is important to accent that, because of the known possibility of errors occurring in the marker-based

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approach, marker-less approach is expected to be more accurate. If the correct recognition of the body segments is assumed, this approach theoretically provides more reliable results.

At last, we should discuss the ankle angle results although real comparison of two approaches wasn't done. This part of the data processing is the most influenced by the video quality because resolution limitations are causing image processing algorithms as well as calculation of line angles between heel and fifth metatarsal markers to have high error sensitivity. For example, foot line length is about 30 pixels long which imply that in the case of coordinate determination error in only one pixel, error will be over 3%. This is the calculation for 640 x 480 pixels image resolution while lower resolution implies even bigger errors. Despite this fact, obtained ankle angle graphs showed expected values for the normal gait.

Conclusions

The goal of our research was to apply newly developed markerless tracking technique and to explore the possibilities of its implementation in clinical analysis of human gait. Markerless results showed high correlation with their marker counterparts. Average differences were low and the obtained trajectories, in general, could be used for the clinical gait analysis. However, some deviations were detected and further research is required. In order to expand tracking to other types of motions, computer vision algorithms should be developed further.

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