MARKER-FREE ANALYSIS OF HUMAN GAIT

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Abstract: A newly developed marker-free human motion analysis system is presented in this paper. Authors describe the principles, methodologies and algorithms designed for this system in order to get human gait data in an easy and less expensive way. The marker-free analysis system aims to reproduce the performance of current commercial marker-based motion capture systems. It can run using the conventional cameras and without the use of any other equipment or special apparel. Moreover, the first group of healthy young people was analysed to verify the system functionality and its applicability in clinical environment. The achieved kinematical data were also used to create a normative gait database, which is needed to evaluate pathological gait in patients with various diseases of motion apparatus.

Introduction

A visual examination of human locomotion as well as human gait represents an easy way how to evaluate quality of subject's motion. This qualitative and subjective approach is also termed as visual gait analysis and its disadvantage is that the identical deviation from normal gait patterns can be classified once as slight or soft, and at another time as serious. Due to this fact it can be considerably unreliable. Another approach, known as objective or quantitative gait analysis, is based on various methods and measurement techniques of human locomotion. Furthermore, human motion and gait analysis is receiving increasing attention not only from many significant clinical specialists, but also from many others interested computer vision researchers. This interest is mainly motivated by a wide spectrum of applications, where the human motion analysis systems can be applied.

There was developed a lot of evaluation processes and appropriate measurement devices in gait laboratories all around the world. These have to satisfy all specific requirements resulting from human gait complexity. Most of the systems, used to capture not only the human gait but also many other dynamical tasks, are based on tracking of small either passive or active markers, attached to the particular anatomical landmarks of patients' bodies according to the specific marker set. Although, these systems are at the very high technological level, use sophisticated methods, are accurate and can be easily operated, there are efforts to develop less expensive and even more available systems. Such systems, the researchers are worked on, are termed as "marker-less" or "marker-free" systems.

Many laboratories work on various methodologies including wearing of special clothing, using of black or highly contrasted backgrounds, complicated edge detection algorithms, background elimination, video-frames processing etc. We have been developed the system, which is able to analyse human gait data without necessity to use any special clothing or contrast background as well as necessity to make any arrangements in gait records. The system analyses the kinematical data of human gait in sagittal plane as it is designed to process data obtained with single camera at the moment.

Materials and Methods

Human motion tracking from standard video records becomes a great challenge in the past time. The relatively short history of marker-free analysis brought several innovative methods and techniques. Whatever algorithms are used in such systems, they are based on tools of computer vision. The general principle of designed marker-free analysis system MAFRAN can be described as follows.

First, the subject' gait is recorded with using of any commercial video camera directly into the PC or on the videocassette, in the case that the records are made outside of the laboratory. The frame rate is really important parameter here. The rate around 50 Hz is sufficient for natural and/or slow motions. The highest frame rate is required when the task is to analyse running or fast motions.

After recording, the gait record is transformed onto frame sequence. This should include frames from at least one complete gait cycle, when the goal is to analyse whole cycle. Unlike other marker-free systems, no special arrangements of the frames are required, what makes the analysing process faster.

The model of lower extremity is defined and adjusted to the subject in the next step of analysis. There was created a model of lower extremity consisting of four points and three links in the system MAFRAN. The points are joints of hip, knee, ankle and fifth metatarsal head, and three links represent segments of lower extremity, namely thigh, calf and foot. The model adaptation is necessary to do for one of the frames. In general, it can be any frame of the sequence. The usually selected frame is the first frame of the record or

ISSN: 1727-1983 © 2005 IFMBE

first frame of the gait cycle. The definition is easily made just by four mouse clicks on particular joints. Individual joint are then defined as a block of picture elements (pixels). The process of the model definition is also called the system initialisation. The figure below shows the model adjusted to the subject at the beginning of the swing phase of the gait cycle.

Figure 1: Adjusting of lower extremity model to the one frame of the gait record in the system MAFRAN.

The most important part of the analysis chain follows after above described process of system initialisation. MAFRAN starts to trace motion in whole record or on a defined frame amount automatically. Designed motion tracking algorithm is based on inter-frame prediction with motion compensation. Here, the point's motion between two consecutive frames is defined by vector of motion. The efficiency of motion inter-frame prediction depends on accuracy of vector of motion estimation.

Vector of motion estimation uses correlation characteristics of motion picture. Blocks of pixels, defining the individual points of used model (hip, knee, ankle and fifth metatarsal head), are compared with blocks of pixels taken from the next consecutive frame. All compared blocks have to be the same size. However, this size can vary during tracking and/or can be adjusted by operator. The correlation maximum of two blocks of pixels defines vector of motion of particular joint. Two blocks of pixels correlation is calculated as follows:

$$r(i,j)=\frac{\sum_{m=1}^{K}\sum_{n=1}^{K} J_{F-1}(m,n)J_F(m+i,n+j)}{\left[\sum_{m=1}^{K}\sum_{n=1}^{K} J_{F-1}^2(m,n)\right]^{\frac{1}{2}}\left[\sum_{m=1}^{K}\sum_{n=1}^{K} J_F^2(m+i,n+j)\right]^{\frac{1}{2}}}, \qquad (1)$$

To make tracking process faster it is necessary to decrease the number of calculations. Selecting of small scanning area (SA), which surrounds the selected block of pixels, solved this problem. The size of scanning area depends on velocity of motion, frame rate of used camera and can vary during tracking as well. Then the number of calculations is rapidly decreased. Vector of motion of two blocks of pixels from two consecutive frames is then given by the correlation maximum, and is located in scanning area. This is described by the following formula:

$$\overline{V}=\{(\hat{i},\hat{j}):r(\hat{i},\hat{j})\geq r(i,j);\forall i,j\in SA\}, \qquad (2)$$

The figure 2 shows the scanning area (SA) in the actual frame (F) searching for vector of motion (V) of block of pixels (KxK) from previous frame (F-1).

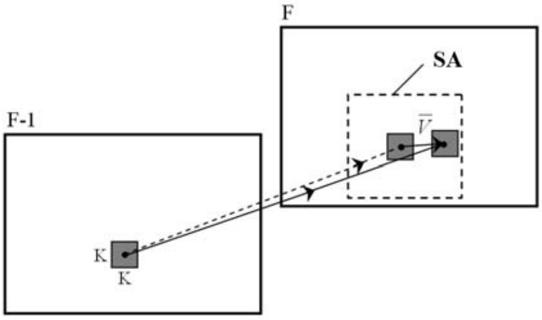

Figure 2: Searching area decreases the number of calculations.

Searching of correlation maximum continues frame by frame for all points of lower limb model. Tracking is stopped at the end of frame sequence or earlier by the operator to be able to check currently reconstructed trajectories. The block diagram of motion tracking algorithm is shown on figure 3.

The advantage of the designed methodology is that the tracking can run forward but also backward, and for all points at the same time. It can also run just for one selected point, what is valuable in the case when such point was not selected correctly at the stage of manual initialisation or in the process of trajectory reconstruction.

Having of all reconstructed trajectories enables kinematics parameters calculations. This is done considering the subject anthropometrics parameters. Except of subject's lower extremity joint positions, system MAFRAN calculates and graphically displays their velocities and accelerations, the anatomical joint angles, linked model, and time-distance parameters.

The last step of analysis is data presentation. All the acquired gait data are analysed by the operator and/or clinicians and are presented in graphs and/or numerically. The analysed subjects' data can be also added into the databases for future evaluation and/or for making various statistical comparisons.

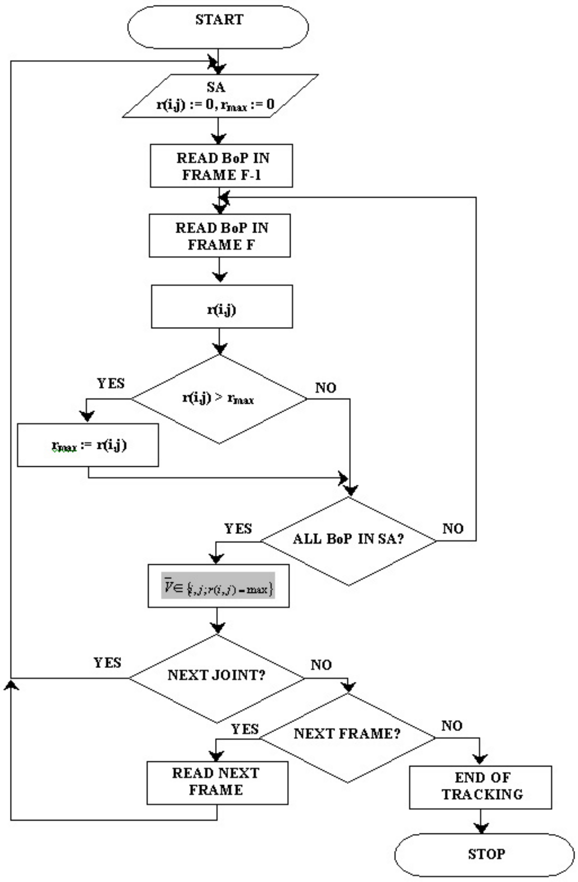

Figure 3: Block diagram of motion tracking algorithm.

Results

The aim of the study was to verify clinical usage of developed system MAFRAN as well as its possible applications. Gait of five young healthy male subjects was analysed with the system as first. Subjects, included in the analysed group, were in the age of 22 to 28 and the average high of was 178,54cm. Each subject was asked to walk in his natural and normal speed. There were taken also anthropometrics measures in all subjects before capture, namely high, thigh length, and calf length. All measures were summarised in the table.

The trajectories of lower extremity joints were reconstructed after recording the gait. A stick figure was used during reconstruction to visualise motion of individual joints and particular body segments. An example of stick figure is shown on figure 4.

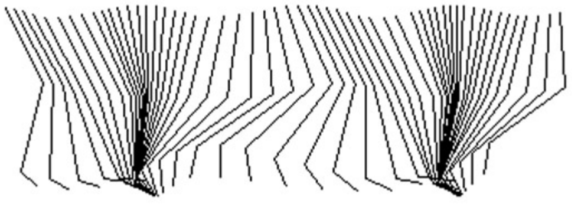

Figure 4: Stick figure of lower extremity model during normal gait.

The following parameters were analysed in all subjects:

- trajectories of motion – positions, velocities and accelerations of individual joint
- anatomical joint angles – hip flexion/extension, knee flexion/extension, and ankle plantar/dorsal flexion
- time-distance parameters – gait cycle length, gait cycle time, gait cycle velocity, cadence (cycles per minute), stance phase and swing phase

To be able to analyse individual parameters in further studies it is needed to create their databases. The gait analysis history brought many methodologies and databases and as it was recognised they usually are different. The most presented are anatomical joint angles.

We used all healthy subjects data to create normative gait database. Designed methodology for its calculation is based on statistical methods.

First, the anatomical joint angles of healthy subjects, considered as the normal data (not pathological), were standardised at one gait cycle. This means that the gait cycle is defined from 0 to 100% and the data of all subjects are defined in identical points of gait cycle, for example, at each 0.5, 1 or 2% of gait cycle. Here, the interpolation seems to be the most suitable as so created curve is going through all control points. The cubic spline interpolation was used in all angles and for all included subject to standardise them.

Definition of normative data was made by determination of reliability interval upper and lower bounds. Reliability interval means that the data included in are the data of normal healthy subject and the data out of this interval represent the pathological case of subject gait. The task was to choose proper value of reliability that is the probability of interval coverage. As for the references in literature and the most used values in mathematical statistics and laboratories we use the probability of 95%. Then the bounds were calculated as follows:

$$\begin{aligned} \theta_{iL} &= \overline{\theta}_i - t_{1-\alpha/2}\frac{s}{\sqrt{p}}, \\ \theta_{iU} &= \overline{\theta}_i + t_{1-\alpha/2}\frac{s}{\sqrt{p}}, \end{aligned} \qquad (3)$$

where $\overline{\theta}_i$ is the mean value of the analysed parameter (anatomical joint angle of lower extremity) with the normal distribution and with the dispersion s^2. p is the number of included healthy subject and $t_{1-\alpha/2}$ is quantile of Student t-distribution with the p-1 degrees of freedom.

Figure 5 shows derived normative gait database of three anatomical joint angles, namely hip flexion/extension, knee flexion/extension and ankle plantar/dorsal flexion angles, for 95% probability of reliability interval coverage.

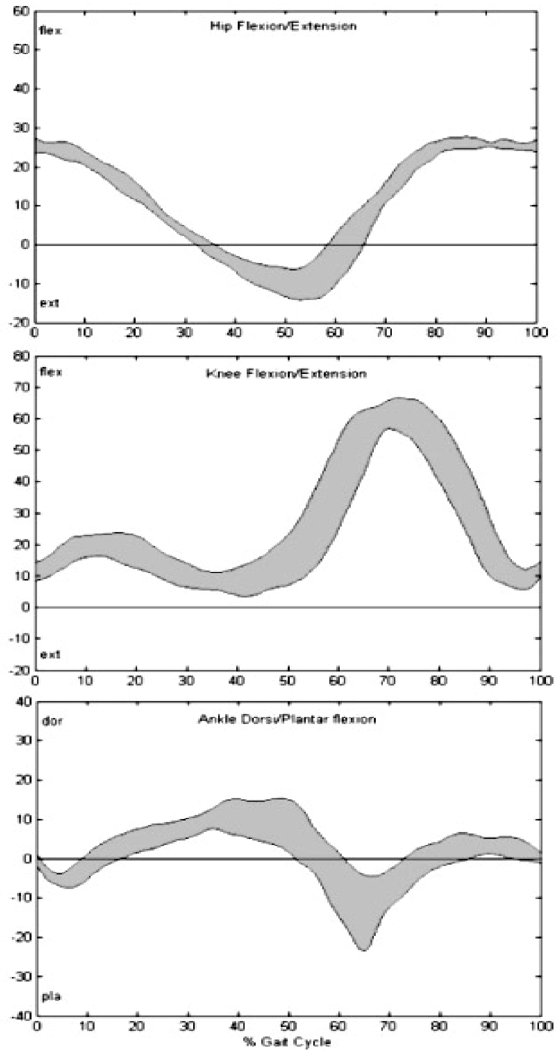

Figure 5: Normative gait database of anatomical joint angles.

Acquired normative gait database can be easily updated with each new analysed healthy subject. On the other hand, pathological cases can be compared with this data, and it will helps the clinicians to make proper decisions and chose the most effective treatment procedures.

Conclusions

Newly developed marker-free analysis system MAFRAN was described in this paper. The system was verified at the group of young healthy male subjects, trajectories of motion, and kinematics parameters were acquired and normative gait database was derived.

The experimental results convinced us that the designed methodology and designed system are clinically applicable. Determination of normative gait database will help in the process of pathological gait assessment. Doing so it is necessary to realise, that the normative gait databases of individual gait laboratories are slightly different. There are several reasons of differences in normative gait databases. It can be the system used for analysis, model of anatomical landmarks and body segments definition, gait parameters calculation methodology, group of subjects' characteristics and/or the operating personnel. The results of various available gait databases comparison confirmed that there still does not exist the standard normative gait database suitable for evaluation of gait data obtained in different laboratories. Therefore, the most objective evaluation of pathological gait is achieved when the data are analysed with the normative gait database acquired with the same system and in the same laboratory.

Acknowledgements

The results in this paper were obtained using of grant from Italian company eMotion "The influence of intensive pre-surgical rehabilitation before total hip endoprosthesis on post surgical status of patients" and VEGA 1/1094/04 "Theoretical principles, methods and tools for human motion analysis."

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