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3D RECONSTRUCTION OF MOTION PATHS DURING STAIR CLIMBING

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ABSTRACT

Computer modeling and simulation can be used to perform three-dimensional biomechanical analysis of human locomotion in order to provide insight into the way of achieving motion in normal and pathological conditions, as well as a diagnostic tool for diagnosing and correcting pathologies and providing a way to optimize the specific activity of locomotor system.

This paper presents a detailed analysis of lower extremity kinematics during stair climbing. To enable the computer 3D biomechanical analysis of human motion, kinematic models have been developed, by which data from marker coordinates captured by the measurement system ELITE can be faithfully imitated.

Based on the spatial position of measuring markers in a reference coordinate system, the three-dimensional computer reconstruction of their trajectories and their projections in the sagittal, frontal and transverse plane has been made. The dependence of coordinates, translation velocities and accelerations of the hip, knee and ankle joint during the stance period have been determined.

Keywords: biological locomotion, stair climbing, computer simulation

1. INTRODUCTION

Tracking of human body motion is applied in many fields, such as virtual reality, clinical biomechanics, the study of man-machine-environment relationship, the analysis of sports movements, etc. Nowadays, the preferred approach to tracking human body motion is based on the use of appropriate optical or magnetic markers, which are placed on specific landmark points, and real-time estimating of their spatial coordinates.

With the improvements introduced in computerized monitoring of human motion kinematics, it is important to emphasize the significance of combining motion capture data with commercial CAD packages.

The aim of this research was to develop new interactive methods in creating virtual anthropometric and antropodynamic models within the highly sophisticated CAD computer technologies, as well as computer simulations for analyzing the various forms of human locomotion. The development of methodology for 3D computer simulation that will truly emulate the real motion of a recorded magnetic and optical monitoring within the CAD system will provide a detailed biomechanical analysis of kinematics and dynamics in various aspects of human locomotion.

One of the aims of this research is to realize the applicability of the developed simulations for diagnostic purposes, in order to recognize gait disorders and to analyse biomechanical parameters with which they could be expressed quantitatively.

Within this research, special attention is focused on the study of locomotion when climbing stairs, as an activity that requires large amount of metabolic energy, and thus represents great difficulty in performing daily activities for people with disorders of the musculoskeletal system, particularly for people with lower limb amputation [1].

2. EXPERIMENTAL MEASUREMENTS

ELITE measuring system, a product of the company Bioengineering Technology & Systems (BTS) from Milan, allows recording of spatial coordinates of markers set on specific anatomic points on the human body and signal processing of recorded data in real time [2,3]. The system may include more cameras, constructed so that they are particularly sensitive to infrared (IR) part of spectrum. Number of cameras that are used depends on the size of the visual field and type of motion that is recorded. For the analysis of 2D problems, where it is necessary to analyse movement in the sagittal plane, in some cases only one camera may be sufficient, while the analysis of spatial problems is performed with the use of multiple cameras. Flashes that are mounted on cameras emit infrared rays that are rejected on the reflective surface of the markers. The sensitivity of the camera only allows detection of light from the markers, while ignoring other sources (skin, cloth, ...). ELITE system uses passive markers, which allow absolute freedom of movement of subjects. Number of markers is not limited, and their diameter ranges from 1 mm to 1 cm.

2.1. Organisation of measurement

Before recording it is necessary to define a configuration for recording and the number of parameters, which include the number of cameras, the number of markers and the number of platforms for measuring of ground reaction forces. For the purposes of this experiment, the configuration with two CCD cameras has been used (Figure 1). Measuring took place in a pre-calibrated working volume of 2.2 m length, 1.8 m height and 1.5 m wide, with a recording frequency of 50 Hz.
The subjects were climbing the stairs that consisted of two steps with the standard slope of 17 cm in height and 29 cm in depth. The first step was mounted with the Kistler force platform for measuring of ground reaction forces. The climbing was performed in two different ways, with the speed that the subjects considered as their slow speed of climbing and with the speed that they considered as their normal speed of climbing. A number of experiments has been repeated for each subject. For further analysis only successfully saved files have been used, where it was possible to reconstruct the cycle of climbing, and where the full contact between foot and the platform has been achieved.

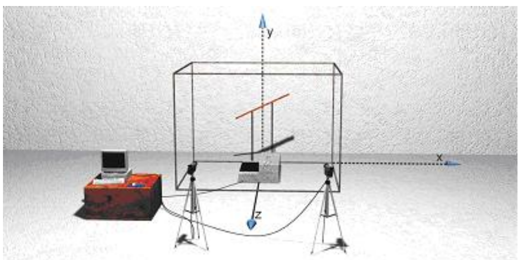
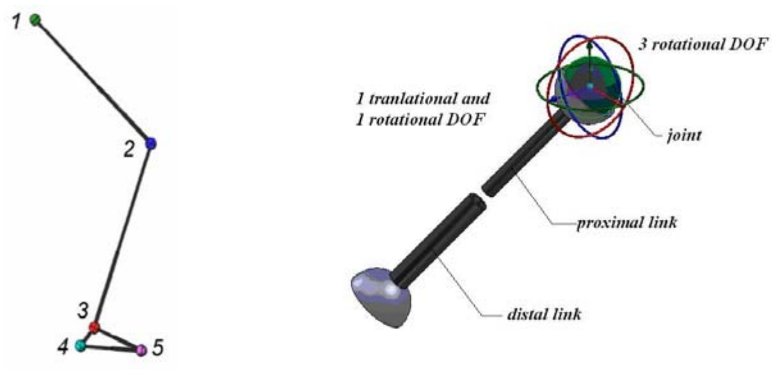


Figure 1. Sheme of the measuring system with the reference coordinate system

In order to correctly interpret the recorded data, it is necessary to classify markers. Markers are numbered and assigned to the appropriate anatomic position on the subject, which forms a 2D model for each camera as a set of points connected by lines. On the basis of this information the stereophotogrametric reconstruction of 3D coordinates of markers can bee done.
Markers were placed laterally to the right leg of each subject, and their position is defined according to the procedure described in (Perry, 1992) and (Cappozzo et al., 1995) [4,5].
The markers of 1 cm in diameter have been used, which are placed on the following five characteristic points.

- marker 1: hip (upper front edge of the great trochanter);
- marker 2: knee (top of the fibula);
- marker 3: ankle (3 mm and 8 mm below the top front of the lateral malleolus);
- marker 4: heel;
- marker 5: the root of the little finger (top of the fifth metatarsal).

Based on the recorded data with marker coordinates, a CAD computer simulation of "kinematic model" motion has been performed. A flexible kinematic model has been constructed (Figure 2a), in which the joints on the position of markers are connected with two links (proximal and distal). There are three rotational degrees of freedom between spherical joints and links, and one translational and one rotational degree of freedom between the proximal and distal links in the direction of their longitudinal axis (Figure 2b). In this way a computer simulation was enabled that accurately mimics the captured data with spatial coordinates of markers.



a) b)

Figure 2. a) Kinematic model, b) Display of degrees of freedom (DOF) between links (proximal and distal) and spherical joints

2.2. Results of measurement and simulation

An example of time dependence of x, y and z marker coordinates during normal speed climbing is shown in Figure 3.

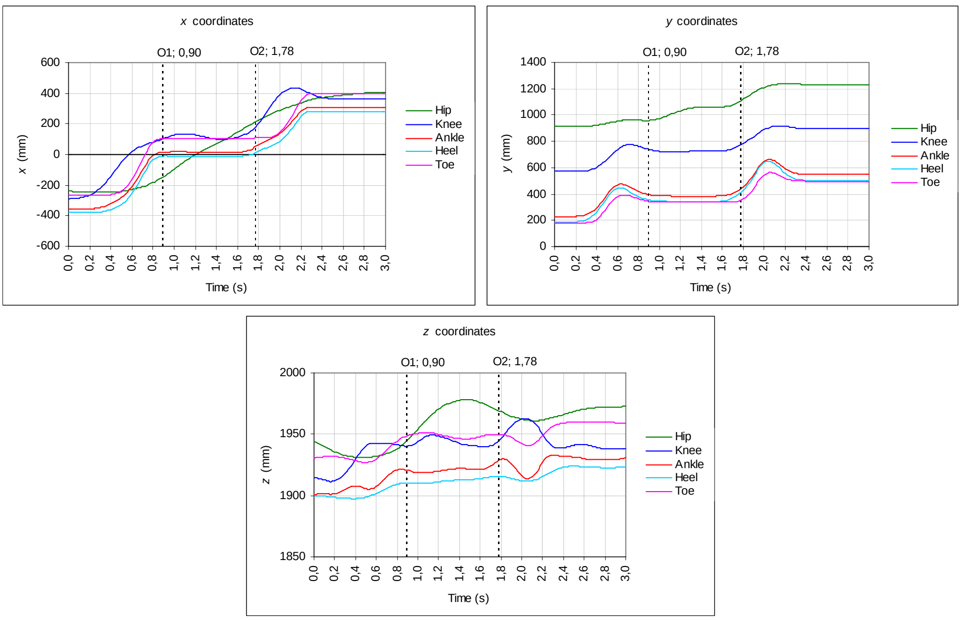


Figure 3. The example of measured data

Tags O1 and O2 in the charts (Figure 3) represent moments of start and end foot contact with the force platform (stance period). The dependence of translation velocities and accelerations of the hip, knee and ankle joint during the stance period have also been determined.
Based on the recorded data, the input files for the CAD simulation software have been defined and the 3D paths of markers have been reconstructed (Figure 4).

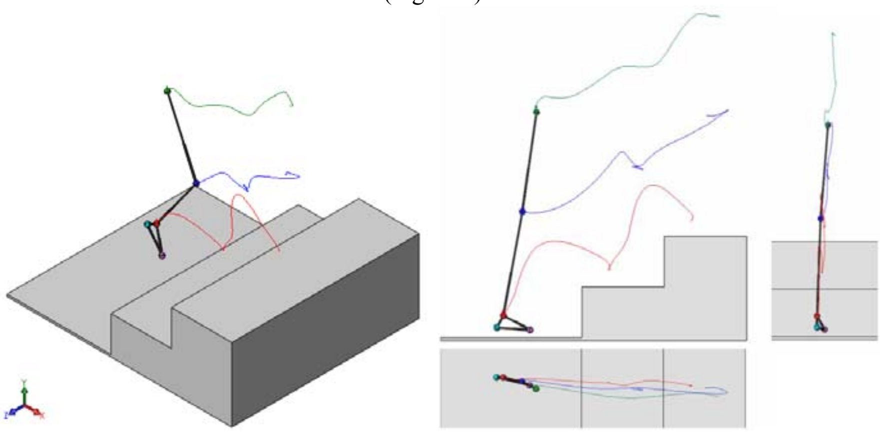


Figure 4. The constructed paths of markers in sagittal, frontal and transverse planes

3. CONCLUSION

The possibilities of computer simulation of moving structures give more information than any other visual means, such as drawings, photographs and video projections, because it is possible to emphasize certain phases, subphases, and the key structural units for the analysis of motion. In order to achieve a 3D biomechanical computer analysis of human body motion, the "kinematic models" have been developed, which precisely mimic data with marker coordinates captured by the ELITE measuring system. In biomechanical tests, due to extreme complexity of the structure of human body, structural diagram of the human skeleton is usually displayed in the form of mechanism composed of members, which are connected in a series of kinematic chains. The kinematic model of lower extremities developed in this research consists of 15 members (5 joints and 10 links). The mobility of the system is realized through three rotational degrees of freedom between the individual joints and links (spherical joints), and through one translational and one rotational degree of freedom between the proximal and distal links in the direction of their longitudinal axis (cylindrical joints). The spatial positions of the recorded markers in the reference coordinate system have been defined by the computer processing and a three-dimensional reconstruction of their trajectories and their projections in the sagittal, frontal and transverse plane has been performed.

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