

Method to simultaneously measure 3D kinematic and kinetic data during normal level walking using KISTLER force plates, VICON System and video-fluoroscopy.

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Abstract—Force (kinetic) and opto-electrical motion tracking (kinematic) measuring techniques are well established to analyse gait and other movement patterns. During the last years, video-fluoroscopy became a new and well accepted technique to get accurate kinematic information of artificial joints in vivo by a three dimensional numerical reconstruction of the single plane projection view of fluoroscopic images. The method presented allows to simultaneously acquiring kinetic and kinematic data with KISTLER force plates, VICON system and a moving video-fluoroscopic system during normal level walking. This new combination of measuring techniques allows an improved analysis of load and movement of the human body.

Keywords-component; 3D-kinematic, force measurement, movable video-fluoroscopy, level walking

I. INTRODUCTION

Accurate in vivo kinematic and kinetic analysis of total knee arthroplasty is important to understand the complexity of knee joint mechanics. This knowledge is crucial to prevent higher stress and strain on the ligaments as well as in the implant parts.

Instrumented gait analysis is a well established method to collect non-invasively kinematic and kinetic data of the knee joint and thus estimate the functionality of joints [1], [2]. Optical markers are placed on the subjects extremities to gain kinematic information, while force plates fixed on the ground simultaneously measure the ground reaction forces. However, the main problem of this approach is the error caused by skin movement artefacts [3], [4],[5].

Single plane video-fluoroscopy is a method which enables a more accurate reconstruction of the three dimensional position and orientation (pose) of the implant components by avoiding errors due to skin and muscle movements [3]. A registration algorithm estimates the pose of the implant components from the single plane projection view of the fluoroscopic image series [6], [7], [8].

Studies on knee joint kinematics and kinetics by means of force plates and video-fluoroscopy have already been performed, but the individual data has not yet been acquired simultaneously [9].

A moving video-fluoroscope system was build to track the knee joint during level walking and thus to collect kinematic data of several gait cycles [10],[11].

The goal of this study was to build a system which allows to simultaneously acquire kinematic and kinetic data during level walking using a moving video-fluoroscope, VICON motion tracking system and KISTLER force plates.

II. MATERIALS AND METHODS

A. Experimental setup

In order to gather X-ray images of the knee during level walking, the C-arm of the fluoroscope (BV Pulsera, Philips Medical Systems, Switzerland) was fixed on a motor driven cart (unit mover) that constantly tracked the position of the knee joint keeping it within the field of view of the imaging unit. The subject can thus walk down the approximately 12 m long walkway of the laboratory without any restriction. Reflective markers fixed on the C-arm and on the subject are recorded by VICON System (Oxford Metrics Inc., Oxford, UK). The kinetics was measured simultaneously by five KISTLER force plates (KISTLER Instrumente AG, Winterthur, Switzerland).

1) KISTLER force plate

The ground reaction force was measured by five 400x600 mm multi-component force plates based on piezoelectric sensors. They are mechanically separated from the surrounding floor to decouple the influence of vibration from the unit mover. The force data are sampled with 1kHz.

The centre of pressure of the force is corrected by the method introduced by Dettwyler [12], which increases the accuracy to less than ± 1 mm on the surface of the plate.

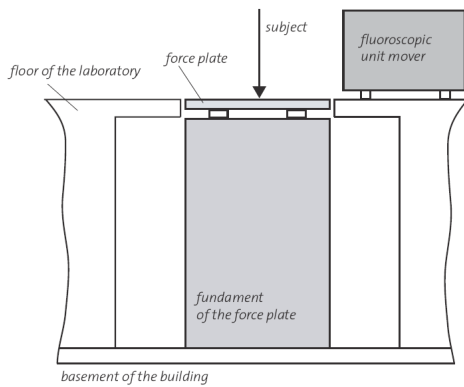


Figure 1. The force plate is completely decoupled from the surrounding floor. The Figure illustrate the force plate and its sensors mounted on a separate support of the building.

2) Optical tracking system VICON

8 to 12 cameras of the VICON System (V612 MX40) are calibrated to a volume of about 2m x 4m x 2m. The sampling frequency corresponds to a maximum of 500 Hz. The accuracy of the system in the measuring volume was ± 1 mm.

3) Moving video-fluoroscope

The C-arm of the fluoroscopic unit (x-ray source, image intensifier) was separated from the fluoroscopic unit and mounted on the unit mover. The 8 m long cable between the C-arm and the X-ray generator enables the unit mover to cover a distance of approximately the length of the walkway, i.e. 12 m. The acceleration and deceleration of the unit mover was controlled to maintain the knee joint within the field of view of the fluoroscope.

The video-fluoroscope X-ray images were taken with 25 Hz with a shutter time of 8 ms. The tube measures 12" in diameter.



Figure 2. Unit mover with C-arm during an experiment.

4) Distortion correction of the fluoroscopic images

Before each measurement cycle, a calibration grid was positioned in front of the image intensifier and a corresponding X-ray image was taken to correct the distortion of the images. The X-ray images gathered during the measurement are then corrected by means of a bilinear transformation determined between the known and measured points of the calibration grid.

5) Calibration of the fluoroscopic images with reference to the laboratory coordinate system

The laboratory coordinate system (global coordinate system) was calibrated to the kinematic (VICON) and kinetic (KISTLER) coordinate system by the calibrating process of the VICON system. The calibration of the video-fluoroscopic system with respect to the global coordinate system needed more steps. A calibration grid was fixed in a defined position over one force plate. The unit mover was placed so that the grid was seen in the fluoroscopic image. The positions of the markers on the C-arm are measured simultaneously by VICON. Knowing the position of the calibration grid and the measured positions of the markers, a transformation matrix between focus of the fluoroscope and global coordinate system were calculated.

6) Synchronisation

The pulse signal of the video-fluoroscope was connected to the analogue input of the VICON system and sampled with 1kHz, synchronising the two systems to less than 1 ms.

7) Three dimensional reconstruction of the implant's pose

A three dimensional analysis of each fluoroscopic image was achieved by fitting a synthetic X-ray image of the implant component (CAD model) to the original X-ray image [13]. The implants six degrees of freedom of the implant components relative to the focus of the fluoroscope were found by an iterative minimisation of the difference between the synthetic and the original image.

III. DISCUSSION AND CONCLUSION

The presented measuring system takes the conventional gait analysis a step forward. It enables the acquisition of force-plates, photogrammetry and video-fluoroscopy data during the same measurement series of level walking and other human movements. Hence, the kinematics and kinetics of total knee arthroplasty can be studied more accurately than it could be achieved so far by gait analysis systems based on skin mounted markers due to the avoidance of skin movement artefacts. Furthermore, video-fluoroscopic images, kinematic and kinetic information measured simultaneously account for a more reliable estimation of the resultant forces and moments by accurately reducing ground reaction forces into the finite axis of rotation at each time step.

The moving video-fluoroscopy system coupled with force plates allows the subject to walk freely without any restriction, thus obtaining the subject's usual gait pattern while simultaneously gathering kinematic and kinetic data. First results of a pilot study will be published by Zihlmann et al. [14].

The disadvantage of this measuring technique is the exposure of X-ray.

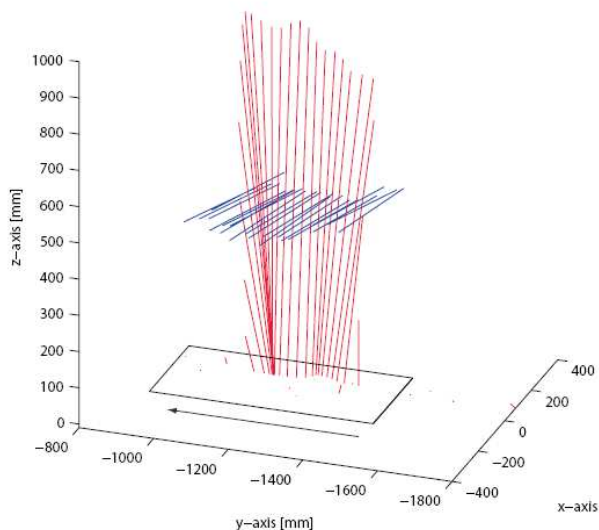


Figure 3. Finite axis of rotation between the implant components of a total knee arthroplasty and force vectors of one force plate. $\Delta t = 40$ ms. Walking direction from right to left.

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