THE KINEMATICS OF THE SWING PHASE OBTAINED FROM ACCELEROMETER AND GYROSCOPE MEASUREMENTS

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Abstract. The kinematics needed to calculate the knee moment during the initial swing phase were obtained from a set of eight leg-mounted uni-axial accelerometers and two gyroscopes. The angular and linear accelerations of shank and thigh were calculated from the signals of two accelerometers mounted on each of the leg segments directed tangentially and radially to the movement. The angular velocities of shank and thigh were measured by the gyroscopes. The absolute angles of shank and thigh were obtained by integration of the gyroscope signal plus an added offset angle, estimated from radial and tangential accelerometer signals registered while standing. Movement was assumed to be in the sagittal plane.

The accuracy of the quantities found from the leg mounted sensors was calculated in terms of correlation and the RMS error by comparing against measurements obtained by a VICONTM system. The results were indistinguishable. The system was later applied in research measurements.

INTRODUCTION

The initial swing phase of gait occurs between 60% and 73% of the gait cycle. Since there is no contact with the floor, to obtain the total net moment around the knee M_{ok} , using the inverse dynamics approach, equation 1 must be solved:

$$M_{ok} = I_{o1} \dot{\omega}_1 + m_1 a_{k1}^t l_{c1} + m_1 g l_{c1} \sin \phi_1 \quad (1)$$

To do this, the angular acceleration of the shank $\dot{\omega}_1$, the linear acceleration of the knee a_k^t and the absolute angle of the shank with the floor ϕ_1 must be found. The moment of inertia I_{o1} , the mass m_1 and the distance to the center of mass of the shank l_{c1} can be obtained from tables [1].

Optical movement analysis systems that track markers are very good at finding linear and angular displacements. But given the large amount of noise introduced by double numerical differentiation, accelerations, as given by systems such as the ViconTM, an alternate method for obtaining these values was developed.

METHODS

Four pairs of uni-axial accelerometers were mounted on two aluminium strips. The strips were placed anteriorly on the left thigh and shank of young male volunteers. The eight accelerometers measured the tangential and radial accelerations at points i and $i+1$ of each segment (figure 1). The distances between the sensors and the proximal joint (hip or knee) were measured with a measuring tape. A gyroscope was attached to the midpoint of each aluminium strip to measure the angular velocity. Data were recorded at a sampling frequency of 100 Hz.

Figure 1. Positioning of the accelerometers and gyroscopes on the thigh and shank

Calibration recordings were made before and after each subject to estimate gains and offsets for all the sensors used.

An optical motion measurement system (ViconTM) was used simultaneously to also obtain the kinematics of the leg segments in the sagittal plane. Reflecting markers were placed at the centers of rotation of the left ankle, knee and hip. The position of the markers was tracked by the ViconTM system using a sampling frequency of 50 Hz.

From the data of the two measurement systems, the absolute angle, the angular velocity, and the angular

acceleration of the shank, and the linear acceleration of the knee were calculated. The formulas for the calculations based on the leg mounted sensors are in [2].

To detect the different phases of the gait cycle, foot switches under the left heel and the left big toe were used.

RESULTS

The data in each of the figures are single trials that were recorded simultaneously by both systems, figure 2 while walking at normal speed; figures 3 and 4 while walking fast.

Figure 2. Absolute angle of shank. Optical markers, solid line; first integral of gyroscope, dashed line

Figure 3. Angular acceleration of the shank. Accelerometer setup, solid line; first derivative of gyroscope, dashed line

Figure 2 shows a typical result of the absolute angle of the shank. The curves obtained from the gyroscopes and from the Vicon™ system are so close (correlation coefficient = 0.995, RMS error = 0.026, normalized rms error = 0.054) that they can hardly be told apart.

The curves in figure 3 are again very close (correlation coefficient = 0.987, RMS error = 2.23, normalized rms=0.142). Both were obtained from the leg mounted sensors.

In order to make the comparison with the angular acceleration given by the optical markers (figure 4) it was necessary to process the raw marker data, as the accelerations as given by the Vicon™ system were not usable. They were treated in the exact same way as the leg mounted sensors. Again the results of comparing the two are very close (correlation coefficient=0.9889, RMS error = 128.5228, normalized rms=0.1564).

Figure 4. Angular acceleration of the shank. Accelerometer set up, solid line; optical markers, dashed line

DISCUSSION

The leg mounted sensors give an accurate representation of all the angles, velocities and accelerations and allow the accurate calculation of the net moment around the knee during the swing phase. Thus, this system was used for swing phase measurements, described elsewhere [3].

Some of the calculations needed to extract the quantities from the sensor data are quite intensive. So the full leg-mounted system is only suitable for off-line applications.

Given the system's portability and relative low cost, it can be applied in any environment. The strips where the sensors are mounted are more cumbersome than the optical markers, but do not impede movement and allow otherwise impossible measurements to be made.

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