

DYNAMICS ANALYSIS OF ANKLE, KNEE AND HIP JOINT IN SAGITTAL PLANE USING A WEARABLE SENSOR SYSTEM

Rencheng Zheng*; Tao Liu; Yoshio Inoue; Kyoko Shibata; Kun Liu

Department of Intelligent Mechanical Systems Engineering, Kochi University of Technology,
Kami City, Kochi County, 782-8502, Japan, 106404x@gs.kochi-tech.ac.jp

URL: <http://www.lab.kochi-tech.ac.jp/robodyna/>

INTRODUCTION

The joint kinetics analysis of ankle, knee and hip joint during gait in daily activities is fundamental for clinical decisions processing but they are commonly obtained by means of expensive laboratory-restricted equipments like a force plate and an optical camera analysis systems, which need sophisticated computing programs and professional operating procession. For using human kinematics and kinetics to biomedical applications conveniently indoors and outdoors, a wearable sensor system was improved for this study.

METHODS AND PROCEDURES

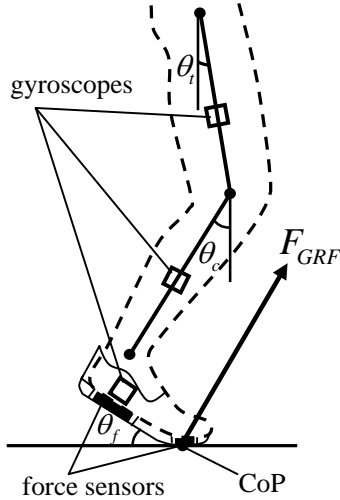


Fig. 1 Leg model wore the sensor systems

A leg model wore the sensor system in the pre swing phase was shown in fig. 1. The wearable sensor system was developed by integrating of a motion sensor system for

detecting kinematical information of lower limb, an instrumented shoe for measuring ground reaction force (GRF) and center of pressure (CoP), and a logger for collecting data.

3 gyroscopes units were worn on the part of the foot, calf and thigh respectively as was shown in fig. 1. Two force sensors were inserted into a modified common shoe as a prototype of the instrumented shoe. One was under the heel part of the shoe, and another under the forefoot part of the shoe. The data logger was strapped around the waist part.

The identification of detailed phases in stance phase is based on the signals of the foot angular displacements θ_f . When $\theta_f > 0$, gait phase is being in weight acceptance, and $\theta_f = 0$ in single limb support, and $\theta_f < 0$ in pre swing.

Position and orientation of ankle, knee and hip joint, in a global coordinates system, can be sequentially estimated based on the identification of gait phase by equation (1), (2) and (3) respectively.

$${}^s\{P\}_{ank} = \{{}^s\{P\}_{ank-wa}, {}^s\{P\}_{ank-sts}, {}^s\{P\}_{ank-pw}, {}^s\{P\}_{ank-sw}\} \quad (1)$$

$${}^s\{P\}_{kne} = \{{}^s\{P\}_{kne-st}, {}^s\{P\}_{ank-sw}\} \quad (2)$$

$${}^s\{P\}_{hip} = \{{}^s\{P\}_{hip-st}, {}^s\{P\}_{ank-sw}\} \quad (3)$$

In whole gait cycle, the joint moments at the ankle, knee and hip joint in global coordinates systems are calculated using the inverse dynamic equation by

$${}^sM_{k,k+1} = -({}^s r_{CoP} - {}^s r_{k,k+1}) \times F_{GRF} - \sum_{i=1}^k [({}^s r_i - {}^s r_{k,k+1}) \times m_i \cdot g] + \sum_{i=1}^k [({}^s r_i - {}^s r_{k,k+1}) \times m_i \cdot a_i] + \sum_{i=1}^k \frac{d}{dt} (I_i \cdot \theta_i) \quad k = 1, 2, 3 \quad (4)$$

The joint powers were computed as the scalar product of the joint moment and joint angular velocity in the global coordinates frame.

RESULTS

By gait experiments of 12 subjects, the joint kinetics is calculated using data measured synchronously by the wearable sensor system and a traditional analysis system of a force plate and an optical camera system. The root mean square (RMS) difference of the ankle moments using the two systems was (2 ± 0.34) (mean \pm standard deviation) Nm, being $(5.4 \pm 0.7)\%$ of the maximal magnitude. The RMS difference of the knee moments was (7.2 ± 1.34) Nm, being $(6 \pm 0.32)\%$ of the maximal magnitude. The RMS difference of the hip moments was (11.2 ± 1.3) Nm, being $(6.1 \pm 0.25)\%$ of the maximal magnitude. The RMS difference of the ankle power calculated by using the two systems was (4.2 ± 0.4) W, being $(8.4 \pm 0.4)\%$ of the maximal magnitude. The RMS difference of the knee powers calculated by using the two systems was (5.7 ± 2.1) W, being $(4.1 \pm 0.5)\%$ of the maximal magnitude. The RMS difference of the hip joint powers calculated by using the two systems was (5.7 ± 0.3) W, being $(6.4 \pm 0.4)\%$ of the maximal magnitude.

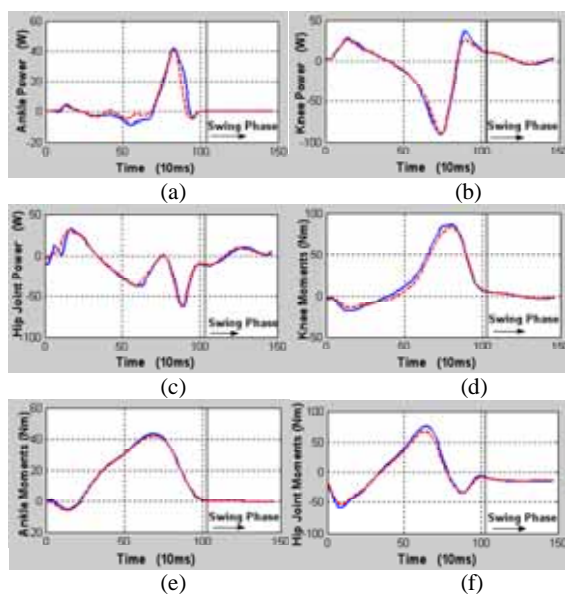


Fig. 1 Joint moments and joint powers estimated using wearable sensor systems (solid line), and force plate & Hi-DCam camera systems (dashed line). (a) Ankle moments. (b) Knee moments. (c) Hip joint moments. (d) Ankle powers. (e) Knee powers. (f) Hip joint powers.

DISCUSSION

In our study, the joint kinetics analysis during whole gait phases on level walking using the wearable sensor systems is presented. An inverse kinetics method integrating of the sensing signals and gait characteristics is developed as a first attempt to estimate the joint kinetics.

SUMMARY

The experimental results testified the joint kinetics assessment of ankle, knee and hip joint based on wearable sensor systems is feasible as well as effective for a daily application of gait analysis.

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