MICROPROCESSOR BASED INCLINOMETER SENSOR FOR USE IN FES

S. Sauermann*, E. Unger*, P. Protz**, M. Bijak*, D. Rafolt*

* Department of Biomedical Engineering and Physics, Medical University of Vienna, Austria

** Fachhochschule Technikum Wien, Vienna, Austria

Abstract

In this work an inclinometer type sensor device was developed. It is intended for measuring the tilt angles of body segments as feedback inputs for control systems in FES. The device is based on a two axis solid state accelerometer sensor, with a microcontroller for signal analysis. It provides 80 digital samples/s over the serial interface. The angular resolution is 0.5 degrees. The absolute error was always below ±4 degrees. There is no need for frequent calibration. Trial measurements of the shank angle during slow walking showed, that the output of the sensor is severely disturbed during fast movements. The system may therefore only be of use in slow movements that do not involve strong transient accelerations: for example standing up, standing, and sitting down. It is intended to use gyroscope sensors for compensation in order to the system more generally applicable.

Introduction

Although an increasing number of commercial systems for Functional Electrostimulation (FES) have become available recently, only very few of them use feedback from sensors for monitoring and control. This may be in part due to the lack of proven sensor systems that support the use in everyday life without adding too much complexity.

Inclinometer sensors have been used in FES. Williamson describes the use of different acceleration sensors for gait event detection [1]. Cikajlo successfully used a combination of acceleration and gyroscope sensors for sensing the shank inclination angle during walking [2].

This work was aimed at a rigid, lightweight, easy to use, and reliable sensor system for measuring the tilt of body segments during FES. Multiple sensors on different body segments shall be used to measure joint angles. One main goal was to make the system as small and lightweight as possible, so that it may be fitted into an existing electrode trouser. It was therefore intended to study the feasibility of inclination measurements of body segments during walking with acceleration sensors alone. The static performance was to be tested, and the sensor output should be compared with an optical gait analysis system.

Material and Methods

The gravitational acceleration is measured in two directions using a solid state acceleration sensor ADXL202 (Analog Devices, Norwood, MA, USA). The signals are analysed by a PIC16F876 microprocessor (Microchip Technology Inc., Chandler, AZ, USA). From the two calibrated acceleration values two inclination angles are calculated: (1) the angle alpha between the sensor x-axis and gravity, projected into the sensor plane, and (2) the angle gamma between the sensor plane itself and gravity. Up to four sensors may be monitored by a single decoder, in order to measure joint angles, e.g of the knee by calculating the tilt difference between the shank and the thigh.

Four sensors were manufactured. Each sensor was calibrated at production time, and the calibration parameters were stored into the EEPROM of the microprocessor. For static measurements the sensors were mounted on a testing device, and rotated over the full range of 360 degrees. The sensor outputs were compared to an absolute angle decoder (Art.Nr.: 07301312, Fa. Leine und Linde, Schweden). Regression curves were calculated and the maximum errors were calculated using Excel (Microsoft Corporation, Redmond, WA USA). This was repeated for different tilt angles gamma of the sensor plane. All measurements were repeated one week later, in order to test the long term stability.

Attempts were made to eliminate accelerations of the body segments themselves, for example during heel strike and heel off events. Low pass filters with cutoff frequencies from 45Hz down to 0.5 Hz were applied on the raw acceleration signals before calculating the inclination angles.

Results

The sensor provides 80 samples/s of both angles, alpha and gamma via the digital RS232 interface. It consumes 5 mA at a supply voltage of 6 V.

The angular resolution is 0.5 degrees (alpha) and 1-10 degrees (gamma). The maximal error of alpha was always between ± 4 degrees if gamma was between –75 and 75 degrees. The maximum error for the angle gamma was in the range of ± 5 degrees for gamma greater than 20 degrees. The measurements were repeated one week later without recalibration, and showed no noteable changes. An example of the static tests of the four calibrated sensors are shown in Fig. 1, where the sensor plane was exactly vertical, gamma therefore being zero.

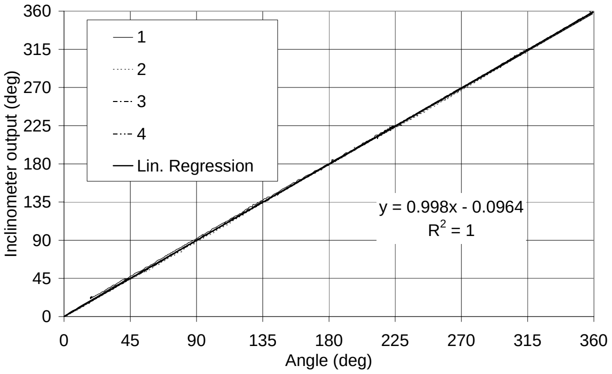

Fig. 1: Example of a static measurement of all 4 sensors. The inclination angle calculated by the inclinometer sensor resembles the tilt angle very closely over the complete 360 degree range.

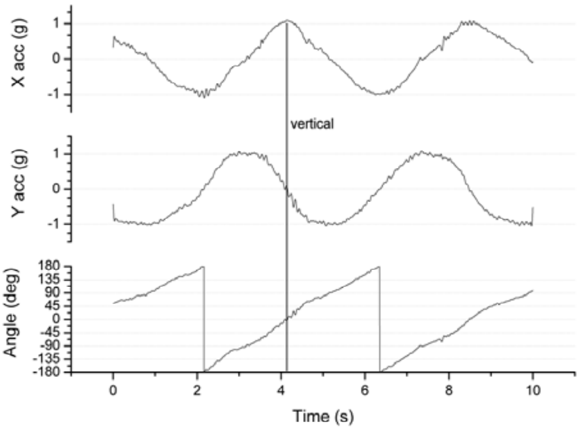

Fig. 2: The sensor output, as a testperson holds it in the hand and slowly rotates it over the full 360 degree range. The sensor plane is near vertical (gamma=0). The bottom trace shows the angle alpha between the x-axis and gravity, projected into the sensor plane.

Fig. 2 shows a trial measurement. The sensor is held by a testperson, which slowly rotates it over the full 360 degrees range. The acceleration signals in the upper two traces of Fig. 2 were filtered with a 45 Hz lowpass filters.

Fig. 3 shows the results of a first measurement of the shank angle on a healthy testperson during slow walking on an even surface, again with 45 Hz lowpass filters. The shank angle signal is distorted by dynamic accelerations. This is especially obvious after the heel on and heel off events. In other trials the distortions were even more dramatic, so that no clean inclination angle signal could be derived.

Low pass filters with cutoff frequencies from 45 down to 0.5 Hz were tested. The inclination angle measurements were not significally improved.

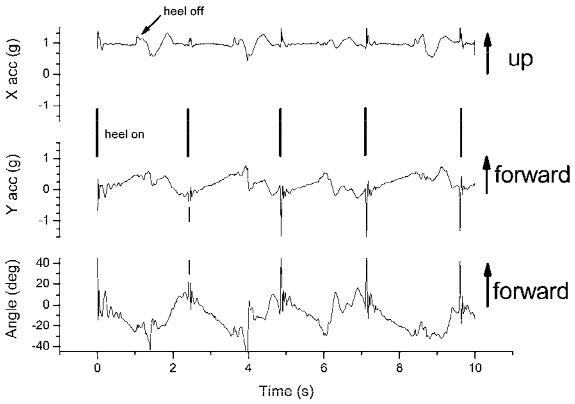

Fig. 3: Shank angle measured with an inclinometer sensor during slow walking. The heel on and off events are marked in the acceleration curves. The angle output is distorted by accelerations of the shank.

Discussion

In this work an inclinometer sensor was developed was tested in static measurements. The inclination angle measurements were found to be accurate and fast enough for applications in FES. First trial measurements of the shank inclination during walking resulted in inclination curves similar to those found in the literature [3]. However, accelerations of the shank disturbed the measurements severely. These components could not be eliminated by low pass filtering, probably because the disturbing accelerations overlap the relevant inclination signal components very much. The comparison of the sensor output to the optical gait analysis system, as initially planned, was therefore not conducted.

We conclude that acceleration measurements alone the way they were used here were not sufficient for measuring body segment angles during normal and fast walking. The sensor in its present form is therefore limited to applications that involve slow movements, without strong transient accelerations: standing up, standing, and sitting down. Future work will involve gyroscope sensors in order to compensate for the accelerations of body segments, as it has been demonstrated by Cikajlo [2].

References

[1] Williamson, R., Andrews, B.J.: Gait event detection for FES using accelerometers and supervised learning. IEEE Trans Rehab Eng, 8 (3), 2000, 312-319.

[2] Cikajlo I., Matjacic Z., Bajd T.: Shank Angle Estimation in Locomotor Training of Incomplete Spinal Cord Injured Persons. Proceedings of the World Congress on Medical Physics and Biomedical Engineering, 2003, Sydney, Australia, 24-29.August

[3] Perry, J.: Gait analysis: Normal and pathological function. Slack, USA, 1992, p89-130.

Acknowledgements

The authors wish to thank Gerhard Kirsch for his major contributions during the design of the circuit and the software.

Author's Address

Stefan Sauermann, PhD
Medical University of Vienna
Department of Biomedical Engineering and Physics
Waehringer Guertel 18-20 / 4L
1090 Vienna, Austria
e-mail: stefan.sauerman@meduniwien.ac.at
home page: http://www.bmtp.akh-wien.ac.at/bmt/home.htm