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„Step length estimation of gait by means of inertial sensors“

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Step length estimation of gait by means of inertial sensors

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INTRODUCTION

The impact of stroke on the life of an individual can be dramatic both mentally and physically. Physically the motor control of one side may be deteriorated. Such deteriorated motor functions can be improved by training. [Liberson1961] proposed in the sixties the use of electrical stimulation to activate dorsiflexior muscle during swing phase of the gait. Since then many systems have been commercialized. Most of these are using footswitches to trigger the stimulation. Miniature inertial sensors might be a good alternative to foot switch sensors to gait phases detection [Kotaidis2004]. The main goal of this work is to investigate the use of inertial sensors for feedback control in Functional Electrical Stimulation (FES)-gait rehabilitation of stroke patients. By means of miniature inertial sensors stride length and foot clearance can be estimated during gait. The intention is to use these values later for automatic control of the intensity of the electrical stimulation in FES-assisted gait.

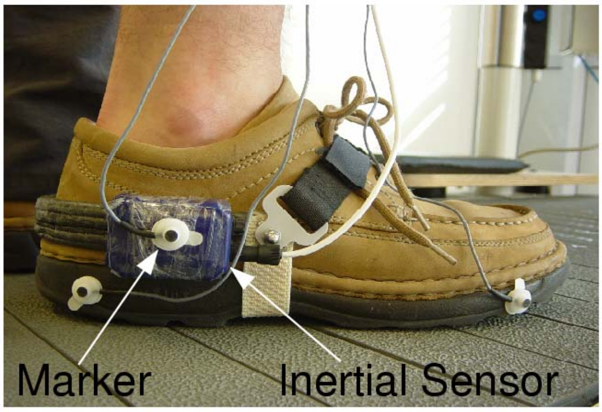

Fig. 1: Experimental setup: Inertial sensor and CMS-HS markers

METHODS

Position and orientation of a foot can be estimated using signals from an inertial sensor consisting of three accelerometers and three gyroscopes. The orientation can easily be found by 3-D-integration of the angular velocity measured with the gyroscopes. This is called an Inertial Navigation System (INS). Even with very good calibrated sensors the estimated orientation will drift off after a very short time. For estimation of the orientation of the sensor with respect to a global coordinate system a Kalman filter was designed. This filter uses the acceleration measurements as a correction to the already estimated orientation based on integration of the gyroscope measurement. The observer is implemented as an indirect Kalman filter, i. e. the error between the integration of the angular speed (INS) and the real orientation is used as state in the Kalman filter. This error is then at fixed intervals fed back to the inertial navigation system to avoid that the error states are becoming too big. The acceleration measurements give additional information of the inclination of the sensor under the assumption that the sensor is not accelerated. A correction of the orientation estimate taking the acceleration measurements into account is thus only applied in the stand phases of the gait. The heading will unavoidably drift off but this is not really a problem for this application.

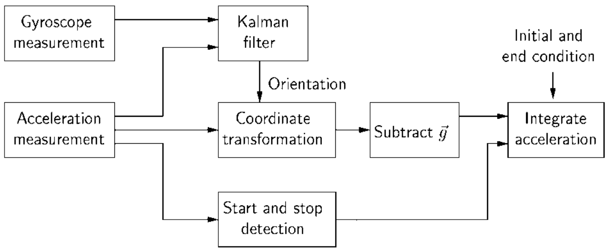

Fig. 2: Block diagram of the step length estimation

Using the obtained orientation the step length and foot clearance can be estimated through a double integration of the acceleration in a global reference system.

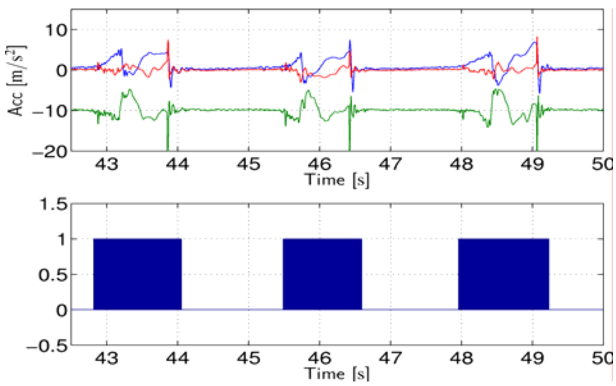

Fig 3: Gait phase detection. Upper graph shows the acceleration. The lower graph indicates the swing phase period

The integration is started and stopped at the beginning and the end of every step. The start and stop times for integration are found off-line after each completed swing phase by considering the absolute value of the acceleration as well as the angle of the sensor in respect to the floor. The acceleration measured in the sensor coordinate system is transformed into a global coordinate system in which the z-axis is in the opposite direction of the gravity and x- and y-axis are arbitrarily chosen orthogonally to the z-axis. The gravity component can now easily be subtracted.

To improve accuracy constraints on the integration are introduced. The velocity of the sensor is assumed to be zero at the beginning and at the end of the movement and the position in the z-direction is identical at the beginning and the end. An artificial bias on the acceleration measurement is employed to obey these constraints.

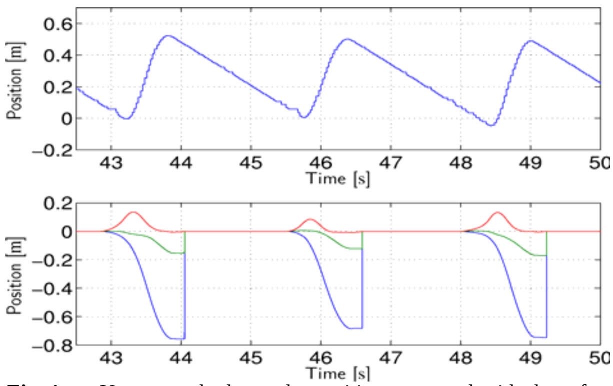

Fig. 4: Upper graph shows the position measured with the reference system, the lower graph shows the position.

In order to evaluate the step length based on the inertial sensors, measurements with a reference system were carried out. The CMS-HS ultrasonic motion analysis system from Zebris company consists of a transmitter system (3 senders) and markers (microphones). The absolute position is calculated based on the travel time of the signal from each of the 3 transmitters. To synchronize the data an interface was implemented in Matlab/Simulink^TM^. Two separate threads were used to collect data from the CMS-HS and the MT9 inertial sensor from Xsens respectively. The CMS-HS position data were sampled with a frequency of 40 Hz and the MT9 with a frequency of 400 Hz. The position data of the motion analysis system were processed off-line and the step length was found by calculating the difference between the maximum and minimum y-position. Additionally, the distance to the belt on the treadmill that was moving while performing a step, had to be considered.

RESULTS

A healthy subject was walking on a treadmill at different speeds (1 km/h, 2 km/h and 3 km/h). Results from one of the tests are plotted in Fig. 5. It can be seen that the estimate is quite accurate and it is also possible to observe changes in the step length. Although the estimation is quite good some outlier are occurring. The standard deviation is around 6 cm. The standard deviation is summarized in Table 1.

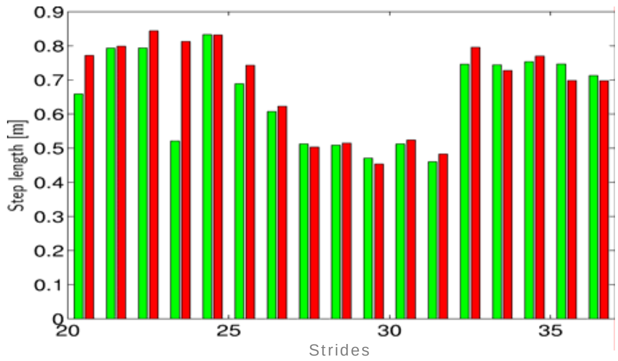

Fig. 5: The calculated step length. The bright bar shows the result of the inertial sensor, the dark bar the measured step length of the reference system

Tab. 1: Mean and standard deviation of the step length estimate

	1 km/h	2 km/h	3 km/h
Std	6.14 cm	5.5 cm	7.6 cm
Mean	2.1 cm	-0.3 cm	0.2 cm
Steps	66	113	144

CONCLUSION

The step length estimation of gait showed good results for normal gait. Although the work done in this paper is done totally off-line it is the prospect of implementing the step length estimation for use in a FES-assisted gait application good. The challenge would then be to identify the start and stop times for the swing phase after a completed step robustly also for a pathological gait pattern, and finish the calculation before next step.

REFERENCES

[Kotiadis2004]
D. Kotiadis, H. Hermens, P.Veltink, P. Slyke, "Inertial Gait Phase Detection system: Design" in *P. 9^th^ Ann. IFESS Conference*, Bournemouth, 2004

[Liberson1961]
W. Liberson, H. Holmquest, D. Scot, M. Dow, "Functional Electrotherapy: Stimulation of the Peroneal Nerve Synchronized with the Swing Phase of the Gait of Hemiplegics Patients", *Arch Phys Med Rehabil* Vol 21, p 101-105, 1961