Münster University of Applied Sciences
Department of Electrical Engineering and Computer Science

Bachelor Thesis

IMPLEMENTATION OF A NEW KALMAN FILTER BASED ORIENTATION ALGORITHM

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A thesis submitted in partial fulfilment of the requirements for the degree of Bachelor of Science in Electrical Engineering

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Statement of Authorship

I hereby certify that this bachelor thesis has been composed by myself, and describes my own work, unless otherwise acknowledged in the text. All references and verbatim extracts have been quoted, and all sources of information have been specifically acknowledged. It has not been accepted in any previous application for a degree.

Granada, 17th February 2015

Robin Weiß

Preface

This thesis was submitted in partial fulfilment of the requirements for the degree of Bachelor of Science in Electrical Engineering. It describes the implementation of a new Kalman filter based orientation algorithm to improve the estimation of the orientation angels obtained with a system called GaitWatch that is used for stance and gait analysis by means of inertial sensors.

I took part in the joint research project "Analysis of anticipatory postural adjustments of Parkinson's patients using inertial sensors" between the Research Centre for Information and Communications Technologies of the University of Granada (CITIC-UGR) and the Department of Neurology of the Klinikum Großhadern in Munich, which is part of the Ludwig-Maximilians University. The goal of this project was to carry out an analysis of the so called anticipatory postural adjustments, which are the movements by a human subject between the moment he initiates gait and the first step. The medical community is interested in this procedure, as it can assist the diagnosis of neurodegenerative diseases such as Parkinson's. Prior to this thesis I completed a three-months internship at the CITIC-UGR in which I worked on the synchronisation of a force measuring plate and the GaitWatch system within the above-mentioned project.

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ABSTRACT

Implementation of a new Kalman filter based orientation algorithm

by Robin Weiß

This thesis was submitted in partial fulfilment of the requirements for the degree of Bachelor of Science in Electrical Engineering. It describes the implementation of a new Kalman filter based orientation algorithm to improve the estimation of the orientation angels obtained with a system called GaitWatch that is used for stance and gait analysis by means of inertial sensors.

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Abbreviations

CITIC-UGR	Research Centre for Information and Communications Technologies of the University of Granada
PD	Parkinson's disease

Notation

$\mathcal{S}$ A set

Chapter 1

Introduction

1.1 General

1.2 Goals

The goal of the project was to analyse anticipatory postural adjustments prior to step initiation and subsequently build a classifier using MATLAB®, which is fed with data from both a force plate and a magnetic inertial measurement unit (GaitWatch [1]), in order to distinguish between Parkinson patients and healthy subjects. To gather the data the subject stood in front of the force plate. Then, the GaitWatch and force plate record was started and the subject made a step onto the force plate. After standing upright for a variable time of two to ten seconds the subject left the force plate, made a few steps, turned left, and stopped in front of it again. This sequence was repeated ten times. From now on we will refer to one of these ten gait cycles as simply a cycle.

1.3 Motivation

Advanced Parkinson's disease (PD) can increasingly diminish the quality of life, due to patients being more dependent on help from others to accomplish daily tasks. New neuroprotective medications are currently being developed and are expected to decelerate or stop the progression of the disease in early stages prior to significant loss of neurons [2][3]. Thus, a quantitative PD classification, enabling early diagnosis of the disease, could optimise early treatment and could furthermore help to validate new treatment methods. Additionally, an objective evaluation of longterm treatment success was ensured.

1.4 GaitWatch

The GaitWatch device [1] is a MIMU designed to monitor the motion of patients while attached to the body. It was developed at the Department of Neurology of the Ludwig-Maximilians University in Munich in conjunction with the Department of Signal Theory, Telematics and Communications of the University of Granada. The system is composed of a set of embedded magnetic and inertial sensors wired to a box containing a microcontroller. This microcontroller is in charge of collecting data from the embedded box sensors, as well as from the external measurement units, and storing them on a memory card. The various units are placed at the patient's thighs, shanks, arms and trunk as shown in Figure **??**. The components of the three different kinds of subunits are described below:

- Type A – thighs and shanks:

  IMU Analog Combo Board with 5 Degrees of Freedom [4] containing an IDG500 biaxial gyroscope (from which only Y axis is actually used) with a measurement range of ±500°/s [5] and a ±3g triaxial accelerometer, ADXL335 [6].

- Type B – arms:

  IDG500 biaxial gyroscope with a measurement range of ±500°/s [5].

- Type C – trunk:

  ADXL345 triaxial accelerometer with programmable range (±2g/±4g/±8g/±16g) [7], IMU3000 triaxial gyroscope with programmable range (±250/±500/±1000/±3000°/s) [8], Micromag3 triaxial magnetometer with a measurement range of ±11Gauss [9], AL-XAVRB board containing an AVR ATxmega processor [10].

1.5 Fundamentals of Inertial Sensors

In addition to the aforementioned subjective rating scales, there are different devices used to quantify gait and posture to assess them objectively. All of them come with certain pros and cons. The following devices have been used:

1.5.1 Accelerometer

Electromyography is a technique for evaluating the electrical activity of skeletal muscles. Successive action potentials generated by muscle cells are measured, by means of needle electrodes inserted into the muscles, and displayed on a cathode-ray oscilloscope. Thus medical abnormalities can be detected. The instrument used to capture the visual recording, termed electromyogram, is called electromyograph [11]. Electromyography is constrained to clinical application only, but in return gives indication about the contribution of specific, individual muscles to APAs.

1.5.2 Gyroscopes

Force plates quantify the ground reaction force (GRF), that is, the force exerted to the human body by the ground. The GRF is a three-dimensional vector with three orthogonal components. One component along the direction of gravity, one parallel to the ground in the sagittal plane, and one parallel to the ground in the frontal plane. Those are vertical planes that divide the body in left and right halves, and ventral and dorsal sections, respectively. A force plate usually gives an electrical voltage proportional to the force in each of the three directions. Force plates can be characterised according to the following criteria: Sensitivity in Volts per Newton, crosstalk (indication of vertical force if a horizontal force is applied and vice versa), repeatability (similar results under the same load), and time- and temperature drift [12]. Usually force plates are embedded in the ground to place minimum constraints on subjects [13]. Therefore they are limited to clinical application. They have the advantage that they don't need to be calibrated before each use.

1.5.3 Magnetometer

Devices that use a combination of inertial sensors like accelerometers and gyroscopes are referred to as inertial measurement units (IMUs). If they also include magnetic field sensors (magnetometers), they are called magnetic inertial measurement units (MIMUs)Magnetic Inertial Measurement Unit. With these devices the orientation of the body can be obtained with up to nine degrees of freedom, provided that triaxial accelerometers, gyroscopes and magnetometers are used, respectively [14].

- ACCELEROMETERS measure the acceleration of an object relative to an inertial frame. Since acceleration cannot be measured directly, the force exerted to a reference mass is obtained and the resultant acceleration is computed according to Newton's second law $\mathbf{F} = m \cdot \mathbf{a}$ [15].

- GYROSCOPES measure angular velocity and are based on the Coriolis Effect. By means of integration of the angular velocity the rotation angle is obtained [14].

- MAGNETOMETERS measure the strength and the direction of the magnetic field in a point in space, using the relationship between magnetic fields, movement and induced currents [14].

MIMUs are portable and relatively inexpensive. They can be easily attached to the body and thus allow non-clinical longterm application. Their drawbacks are complex calibration procedures and drift behaviour over time, depending on intensity and duration of the movement. Hence, in order to maintain a satisfactory degree of precision, periodical recomputation of the calibration parameters is required [14]. Moreover, Mancini et al. [3] pointed out the need of data pre-processing and the question of how to generate a clinically understandable presentation of the movement data.

1.6 Methodology

The team in which I was integrated worked using the agile software development methodology. Working software was delivered frequently and was the principal measure of progression. Our self-organising team consisted of three members meeting regularly. Parts of the software were developed doing pair programming. To follow the progress of other team members at any time we used Pivotal Tracker, a tool for agile project management and GitHub, a repository hosting service based on the distributed version control system Git. I used the document markup language LaTeX to write this report.

1.7 Document Structure

Next, in Chapter 2, we will elaborate on the hardware we used and describe the synchronisation process in detail.

Chapter 2

Fundamentals

2.1 Inertial Sensors

In addition to the aforementioned subjective rating scales, there are different devices used to quantify gait and posture to assess them objectively. All of them come with certain pros and cons. The following devices have been used:

2.1.1 Accelerometer

Electromyography is a technique for evaluating the electrical activity of skeletal muscles. Successive action potentials generated by muscle cells are measured, by means of needle electrodes inserted into the muscles, and displayed on a cathode-ray oscilloscope. Thus medical abnormalities can be detected. The instrument used to capture the visual recording, termed electromyogram, is called electromyograph [11]. Electromyography is constrained to clinical application only, but in return gives indication about the contribution of specific, individual muscles to APAs.

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Force plates quantify the ground reaction force (GRF), that is, the force exerted to the human body by the ground. The GRF is a three-dimensional vector with three orthogonal components. One component along the direction of gravity, one parallel to the ground in the sagittal plane, and one parallel to the ground in the frontal plane. Those are vertical planes that divide the body in left and right halves, and ventral and dorsal sections, respectively. A force plate usually gives an electrical voltage proportional to the force in each of the three directions. Force plates can be characterised according to the following criteria: Sensitivity in Volts per Newton, crosstalk (indication of vertical force if a horizontal force is applied and vice versa), repeatability (similar results under the same load), and time- and temperature drift [12]. Usually force plates are embedded in the ground to place minimum constraints on subjects [13]. Therefore they are limited to clinical application. They have the advantage that they don’t need to be calibrated before each use.

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2.2 Kalman Filter

Chapter 3

State of the Art

Chapter 4

Results and Discussion

4.1 Results

4.2 Discussion

Chapter 5

Conclusion and Future Work

5.1 Conclusions

Summarising the above, I can say that I have learned a lot in the four month that I spent in Granada. Amongst others I have come to know many new work methods, not only due to being exposed to people from a different culture, but also due to the fact that scientific research differs strongly from the work as a student at university. I gained a deeper understanding of Parkinson's disease and how various gait analysis techniques are used to quantify its effects. Therefore I had to study the principles of force plates and inertial measurement units as well as the basics of classification. I was able to improve my MATLAB® skills and have realised how important it is to write understandable and well commented code, if it is for a larger project and not only for a coursework. I am now familiar with tools such as GitHub and Pivotal Tracker which make working in a team much easier and significantly more efficient. Beside my work at the research centre, where I obtained a valuable insight into scientific research, I read a book about scientific writing that helped me to improve my oral and written English skills during my stay. Furthermore I now know the fundamentals of LaTeX.

The above will hopefully serve as a good foundation for my subsequent bachelor's thesis. All in all it was a great experience, professionally as well as personally. I truly recommend such a stay to every university student.

5.2 Future Work

Biomedical research is a very interesting blend of both my major interests, that is, working in the medical field as a paramedic and in the technical field as an electrical engineer. I would like to keep working in this field and write my aforementioned bachelor's thesis here in Granada. There is a variety of possible future work. One related topic would be the validation of the pitch angles measured with the gyroscopes of the GaitWatch by means of cameras that record the trace of visual markers. From these markers one could compute the pitch angels and compare them to the those of the GaitWatch.

A set $\mathcal{S}$

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