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MÜNSTER UNIVERSITY OF APPLIED SCIENCES
Department of Electrical Engineering and Computer Science

Bachelor Thesis

KALMAN FILTERING APPLIED TO ORIENTATION ESTIMATION IN HUMAN BODY MOTION ANALYSIS

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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, 18^{th} March 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 orientation angles by means of inertial sensors.

I took part in the joint research project "Human Body Motion Analysis of Patients with Neurodegenerative Diseases by Means of Inertial Sensors" between the Research Centre for Information and Communications Technologies of the University of Granada (CITIC-UGR), Spain, and the Department of Neurology of the Klinikum Großhadern, which is part of the Ludwig Maximilian University of Munich, Germany. The goal of this project was to obtain several gait parameters by wearable inertial sensors and validate them against conventional methods such as force plates and cameras in combination with visual markers. Physicians and medical researchers are 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 inertial sensors within the above-mentioned project.

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ABSTRACT

Kalman Filtering Applied to Orientation Estimation in Human Body Motion Analysis

by Robin Weiß

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Abbreviations

CITIC-UGR	Research Centre for Information and Communications Technologies of the University of Granada
IMUs	inertial measurement units
MIMUs	magnetic inertial measurement units

Notation

$\mathbf{x}(t)$ The actual state vector of a continuous-time dynamical system at time t.

$\mathbf{y}(t)$ The observation vector of a continuous-time dynamical system at time t.

Chapter 1

Introduction

1.1 General

1.2 Goals

1.3 Motivation

1.4 GaitWatch

This paragraph will describe the hardware we used..

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 1.1. The components of the three different kinds of subunits are described below:

- TYPE A – thighs and shanks:

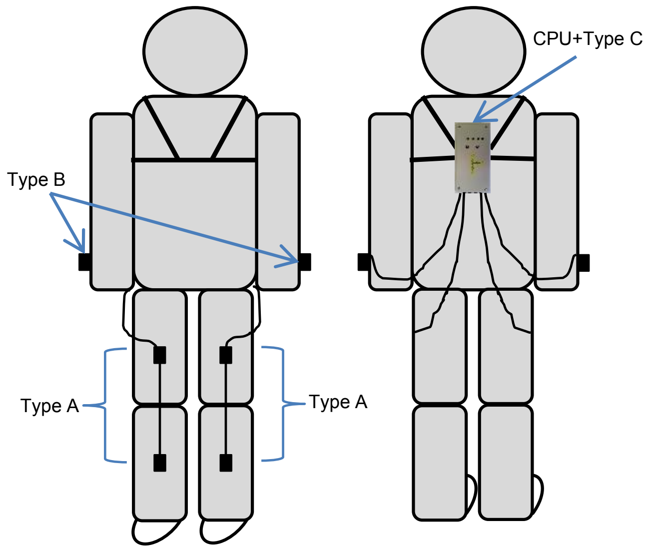

Figure 1.1: Placement of GaitWatch components at the body [1].

IMU Analog Combo Board with 5 Degrees of Freedom [2] containing an IDG500 biaxial gyroscope (from which only Y axis is actually used) with a measurement range of ±500°/s [3] and a ±3g triaxial accelerometer, ADXL335 [4].

- Type B – arms:

  IDG500 biaxial gyroscope with a measurement range of ±500°/s [3].

- Type C – trunk:

  ADXL345 triaxial accelerometer with programmable range (±2g/±4g/±8g/±16g) [5], IMU3000 triaxial gyroscope with programmable range (±250/±500/±1000/±3000°/s) [6], Micromag3 triaxial magnetometer with a measurement range of ±11Gauss [7], AL-XAVRB board containing an AVR ATxmega processor [8].

1.5 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.

1.6 Document Structure

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

Chapter 2

State of the Art

Chapter 3

Fundamentals

3.1 Inertial Sensors

Devices using a combination of accelerometers and gyroscopes to measure the orientation of a solid body with up to six degrees of freedom are referred to as inertial measurement units (IMUs). If they include magnetic field sensors (magnetometers), they are termed magnetic inertial measurement units magnetic inertial measurement units (MIMUs).[9].

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 [9].

3.1.1 Accelerometers

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 $\mathbf{F} = m \cdot \mathbf{a}$ [**?**].

3.1.2 Gyroscopes

Gyroscopes measure angular velocity and are based on the Coriolis Effect. By integrating the angular velocity the rotation angle is obtained [9].

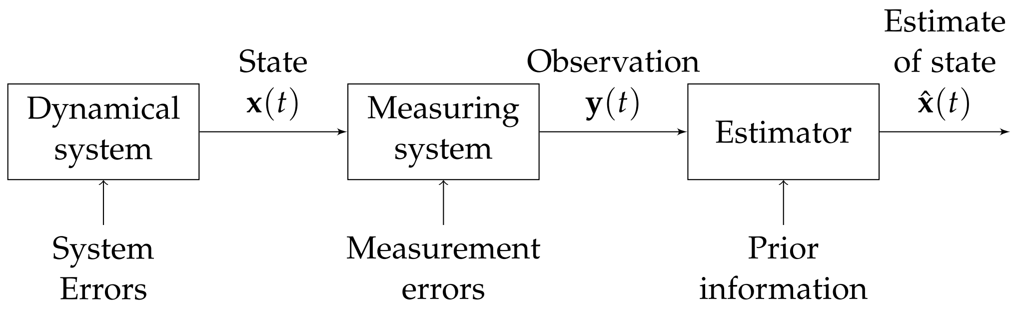

Figure 3.1: Block diagram depicting the components involved in state estimation adopted from [10].

3.1.3 Magnetometers

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 [9].

3.2 The Filtering Problem

Conceived in general terms, a filter is a physical device for removing unwanted components of a mixture. In the technical field a filter is a system designed to extract information from noisy, distorted data. That is, the filter delivers an estimate of the variables of principal interest, which is why it is also called an estimator. Filter theory is applied in diverse fields of science and technology, such as communications, radar, sonar, navigation, and biomedical engineering [10].

Consider, as an example involving filter theory, the continuous-time dynamical system depicted in Figure 3.1. The state vector of the system, $\mathbf{x}(t)$, is usually hidden and can only be observed by indirect measurements $\mathbf{y}(t)$ that are a function of $\mathbf{x}(t)$ and subject to noise. Equally, the equation describing the evolution of the state $\mathbf{x}(t)$ is usually subject to system errors. The dynamical system may be an aircraft in flight, in which case the elements of the state vector are constituted by its position and velocity. The measuring system may be a tracking radar producing the observation vector $\mathbf{y}(t)$ over an interval $[0, T]$. The requirement is to estimate the state $\mathbf{x}(t)$ given prior information.

3.3 Digital Filters

In contrast to analogue filters that consist of electronic circuits to attenuate unwanted frequencies in continuous-time signals, digital filtering refers to applying mathematical operations to a discrete-time signal. A sequence of samples at equidistant time instants represent the continuous-time signal with no loss, provided the sampling theorem is satisfied, according to which the sample frequency has to be greater than twice the highest frequency component of the continuous-time signal.

Digital filters can be classified as linear and nonlinear. If the quantity at the output of the filter is a linear function of its input, that is, the filter function satisfies the superposition principle, the filter is said to be linear. Otherwise, the filter is nonlinear.

3.3.1 Adaptive Filters

Assuming the availability of statistical parameters as the mean and correlation functions of the useful signal and the unwanted noise

3.3.2 Kalman Filters

3.4 Orientation Estimation

Chapter 4

Implementation

4.1 Realisation in Matlab

Chapter 5

Results and Discussion

5.1 Results

5.2 Discussion

A set

Chapter 6

Conclusion and Future Work

6.1 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.

6.2 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.

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