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Assessment of the reliability and validity of a novel 3D motion tracking system for clinical gait analysis

In cooperation with

University of Wisconsin-Milwaukee

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November, 2015

Declaration of Honesty

I hereby declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institute. Information derived from the published and unpublished work of others has been acknowledged in the text and a list of references is given in the bibliography.

Linz, November 25, 2015

Klaus Weissenböck

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Furthermore, I would also express my gratitude towards the Federal Government of Lower Austria, which also granted financial support for my studies abroad.

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NÖ Forschung & Bildung

Above all, I want to thank the University of Wisconsin Milwaukee and in particular my supervisor Kristian O'Connor, for giving me the opportunity to being involved in their scientific work and research projects. I greatly appreciate his guidance, which helped me during my research and writing this report.

fh OBERÖSTERREICH

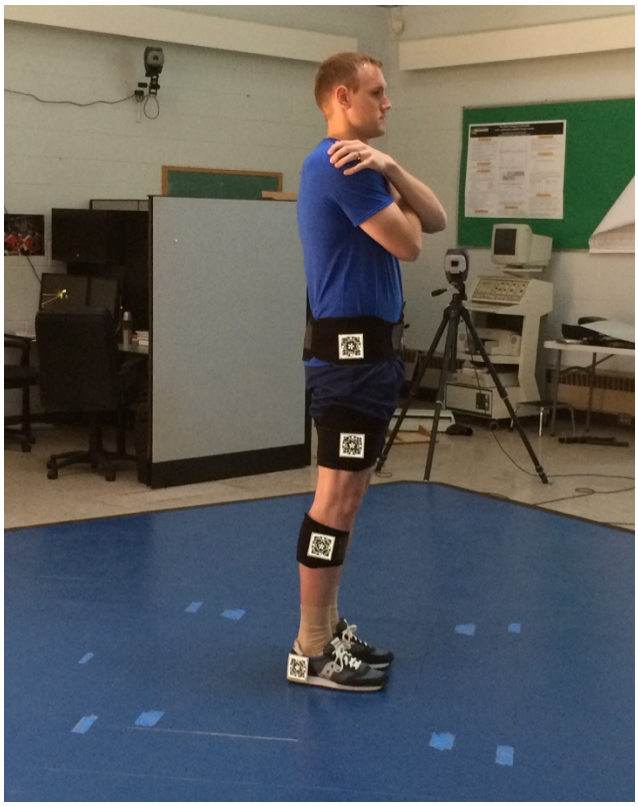
UNIVERSITY of WISCONSIN
UWMILWAUKEE

Special thanks goes to Thomas Haslwanter who supported and advised me expertly prior and during my stay in America.

Executive Summary

The aim of this study is to validate and to prepare the novel single-camera 3D tracking system for clinical introduction. The objective is the robust identification of anatomical landmarks (AL's) and furthermore the identification of hip- and knee-joint centers using a functional approach. Furthermore, a simple and reliable measurement protocol, which reduces errors, was developed. Different approaches of determining joint parameters such as joint locations, and axes of rotation were compared.

MPT-GAIT (Moiré Phase Tracking), as a novel, single-camera 3-D motion capture system, has the potential for 3-D motion capture in a typical clinic, requiring minimal space and technical expertise to operate. The system provides the full 6 Degree-of-Freedom (DoF) 3-D pose of the marker using a single camera!



In comparison to established setups for instrumented gait analysis this is system is very ease to use, space efficient and provides a quick and reliable method of tracking human locomotion. There is also a significant reduction in equipment costs. The implementation of this technology in a clinical environment may have a significant impact on the evaluation and treatment of gait dysfunction. The system provides repeatable results for different observers. Day-to-day intrasubject variations are due to natural variability of walking patterns.

Table of Contents

1 Introduction

This internship in the United States has provided me with the possibility of realizing a project from literature research to running my own study with its associated tasks such as getting ethnical approval, recruiting subjects as well as data processing and analysis. This report provides scientific findings my research project for validating and preparing a novel single-camera 3D tracking system for clinical introduction. This project is a based on a cooperation of the University of Applied Sciences Upper Austria and the University of Wisconsin-Milwaukee.

Gait analysis deals with human locomotion (walking and running) from a biomechanical perspective. Assessment of gait function is an important component of the examination of patients with neuromuscular, orthopedic and cardiopulmonary conditions. Furthermore, the assessment of movement is used in sports medicine to assist athletes to improve performance. Impaired gait function crosses all practice domains of clinical practice and forms the basis of many interventions used in rehabilitation. In order to determine movement-related problems, an easy to use, space-efficient and quick method of obtaining three-dimensional gait mechanics would be desireable.

1.1 Statement of the Problem

Information obtained from instrumented gait analysis can be used by health care professionals to identify specific impairments and to establish treatment plans (Deluca, 1991). Impairment of gait can have a profound impact on a person's quality of life. Consequently, it has a major effect on society since movement-related health problems are becoming increasingly prevalent.

The gold standard for instrumented gait analysis in three dimensions is the use of multi-camera systems. However, these systems are expensive and require a long and tedious setup and measurement procedure. Therefore, simple and accurate movement detection is becoming more important. As a result sound clinical decision making depends on the reliable assessment of gait function (Levine, Richards, & Whittle, 2012). The estimation of different sources of error is thereby important for assessing the reliability of human gait analysis. The literature shows that the reliability of the information obtained by gait analysis can be influenced by factors both intrinsic and extrinsic to the patient: Extrinsic factors such as instrumental errors can be avoided by correct camera setup and camera calibration (Chiari, Della Croce, Leardini, & Cappozzo, 2005). The most critical sources of error are both intrinsic. Soft-tissue artifact, which results from skin movement causing marker displacement (Leardini, Chiari, Della Croce,

& Cappozzo, 2005) and the mis-location of anatomical landmarks (Della Croce, Leardini, Chiari, & Cappozzo, 2005) are sources of error.

1.2 Purpose

The aim of this study is to validate and to prepare the novel single-camera 3D tracking system for clinical introduction. The objective is the robust identification of anatomical landmarks (AL's) and furthermore the identification of hip- and knee-joint centers using a functional approach. Furthermore we planned the development of a simple and reliable measurement protocol, which reduces errors. For that purpose different approaches of determining joint parameters such as joint locations, and axes of rotation were compared.

The problems caused by the sources of error mentioned above were taken into consideration to eliminate errors. To do so, the joint centers and axes of rotation have to be determined robustly and independent of marker misplacement and inter-tester variability (Schwartz, Trost, & Wervey, 2004). This was accomplished by testing different methods of subject calibration, which included a combination of anatomical landmarks and functional approaches of hip- and knee joint center identification (Schwartz & Rozumalski, 2005).

The overall goal of this study is to compare the reliability of different methods of subject calibration on three-dimensional walking patterns.

1.3 Methodical Approach

Figure 1.1 shows the individual steps of the project. It should be noted that the completion of each phase took less than one month.

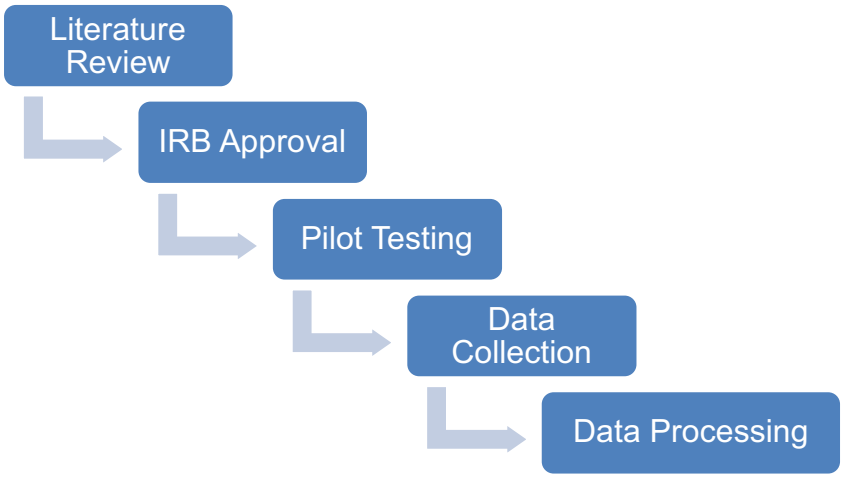


Figure 1.1 Project phases

To start the project and its connected study literature research had to be conducted. This involved general literature on human locomotion and research methods in biomechanics

such as (Levine et al., 2012) and (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2013) as well as more specific papers regarding motion-tracking of human movement (Cappozzo, Della Croce, Leardini, & Chiari, 2005). A summary of the reviewed literature can be found in the appendix.

In order to work with human subject ethical approval for running this study had to be obtained by the universities IRB (institutional review board). The purpose of the review process is to assure that appropriate steps are taken to protect the rights and well being of humans participating as subjects in a research study. A key goal of IRBs is to protect human subjects from physical or psychological harm, which they attempt to do by reviewing research protocols and related materials (Office of Human Research Protections, 2009).

The phase of pilot testing was essential to the project. This phase allowed me to get experienced with the single-camera-system and its associated technologies. Proceeding without testing the software and equipment would have resulted in critical errors during data collection. This phase also comprised necessary software development for data processing and analysis.

Data collection was the most extensive phase of the project; it involved 20 measurements performed by two independent testers. Prior to collecting data, ten subjects were recruited. The goal was to track the three-dimensional aspect of gait with only a single camera. In order to accomplish this task, special (patented) motion tracking markers were used. These markers provide information about two out-of-plane rotations using Moiré patterns. This gave us full six degree-of-freedom position of the marker in space relative to the camera.

Finally, the collected data were processed and analyzed using custom written code that was provided by Dr. O'Connor. However, his program had to be adapted and extended to fit the needs of this particular study. Efforts were taken to create three different data sets for each joint (hip, knee and ankle) and subject to provide evidence for reliable measurement protocols. These data will guide the refinement of the technology and the measurement protocol in order to provide a robust system that can be deployed in a clinical environment.

The validity of the single-camera-system was not tested, since the results from a previous study (Weinhandl, Armstrong, Kusik, Barrows, & O'Connor, 2010) show a good agreement between traditional 3D motion tracking technology and the novel single-camera 3D motion tracking system. The agreement in all three planes demonstrates the ability of the single-camera system to record human movement.

2 Materials and Methods

2.1 Subjects

Ten able-bodied subjects (5 male and 5 female; body mass 63,5 – 107kg; height 1.67-1.93m; age between 18 and 45) participated in this study. The subjects volunteered to participate in testing sessions (1h) across two days (24h to 7days). An informed consent form was read and signed by all volunteers prior to the beginning of the study. The protocol of our study has been approved by the university Institutional Review Board
The following criteria were set for recruiting subjects for the undertaking of the study:

- Participant must not have any current injuries or pain in the low back, hips, or legs
- Participant must not have had an injury to the low back, hips or legs in the last 6 months
- Participant must not be pregnant
- Participant must not have a medical condition that may impair his or her walking ability
- Participant must not be taking medications / drugs that may cause dizziness or tiredness

Height and weight were taken and a medical screening questionnaire was read and signed in order to fulfill the requirements mentioned above. Participants were asked to do several walking trials. In order to track the participant's movement, special markers (targets) were placed on the subject's hip, thigh, shank and foot with elastic Velcro straps. Two independent testers placed these markers. Subjects wore standard laboratory footwear (Saucony Jazz, Lexington, MA). Target trajectories were collected with single-camera 3D motion capture system developed by Metria Innvation, Inc. This system utilized a Basler A501k (Ahrensburg, Germany) 1.3 megapixel camera located 3.5m from the center of the capture volume.

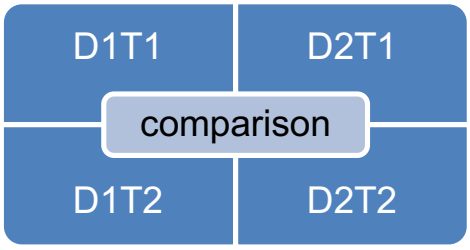


Figure 2.1 Inter- and intra-tester comparison

As described above, two testers (T1 and T2) conducted the collection of the subjects gait data on two days (D1 and D2) (). There are 3 different combinations of subject calibration that were employed based on anatomical landmarks and the functional movement of the knee, which resulted in 3 different calibration processes that were applied to each set of data. The single-camera system is also aimed for users who do not have the possibility of using a force plate in their measurement environment. Therefore we implemented an algorithm that allows the software to process recorded movement data with or without the analog data of a force-plate.

Prior to the study, pilot testing was conducted to ensure that the equipment and the code for data processing were working properly. This way critical mistakes during the actual measurements could be avoided. There was no monetary compensation given to the participants.

2.2 Measurement Equipment

Measurement environment:

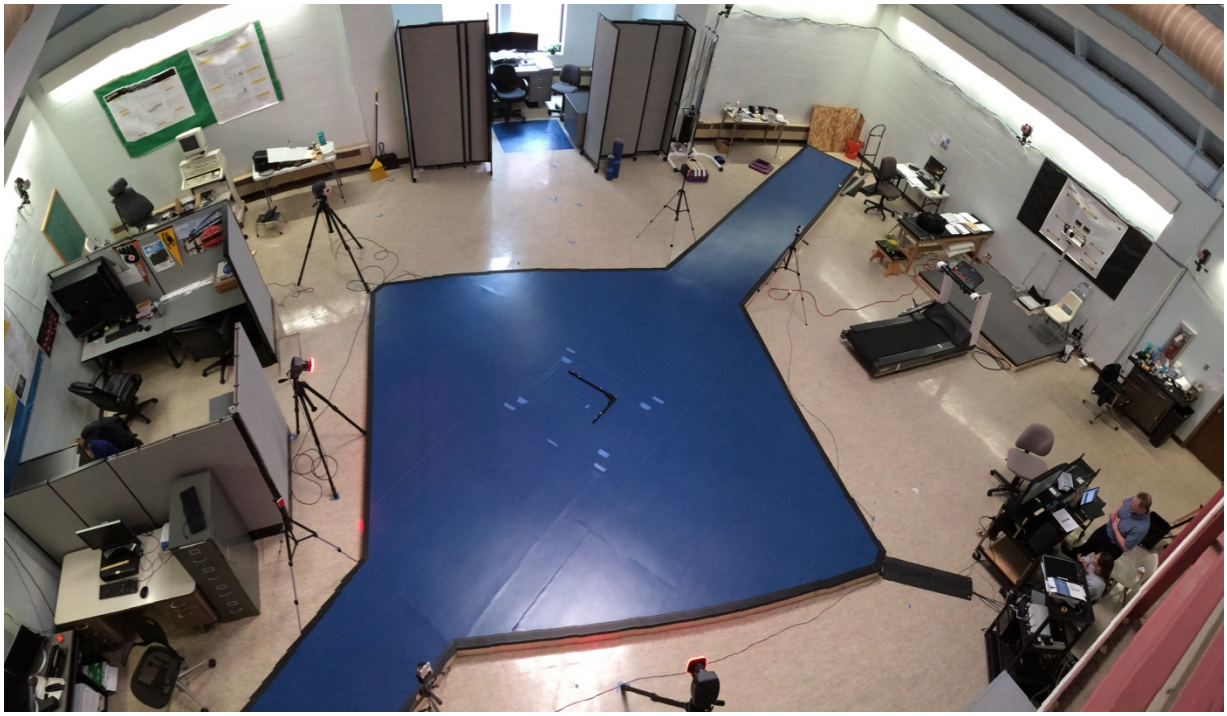


Figure 2.2 Neuromechanis Lab, Enderis Hall - Room 132. This photo shows the lab where all measurements were taken. The force-plate is embedded in the middle of the blue platform. The area in the middle indicated with tape represents the capture volume.

Force-plate: (see Figure 2.2)

The force plate was used to take the participants weight.

- Name: FP4060-NC
- Manufacturer: Bertec Corporation
- Safety: The force plate is embedded into to a platform. The platform is the ground level for the walking trial

Camera-system: (see Figure 2.3)
The camera was used to track the participants' locomotion. The camera system had to be calibrated prior to movement tracking. Therefore, 3 points in the middle of the capture volume were recorded in order to establish a global coordinate system (GCS) in the room using Gram-Schmidt orthogonalization.

- Name: Camera Basler A404k
- MC 40180 Moiré Phase Tracking System™
- Manufacturer: Metria Innovation (Milwaukee, Wisconsin)
- Sample rate: 60Hz
- Safety: The camera is not in physical contact with the participant

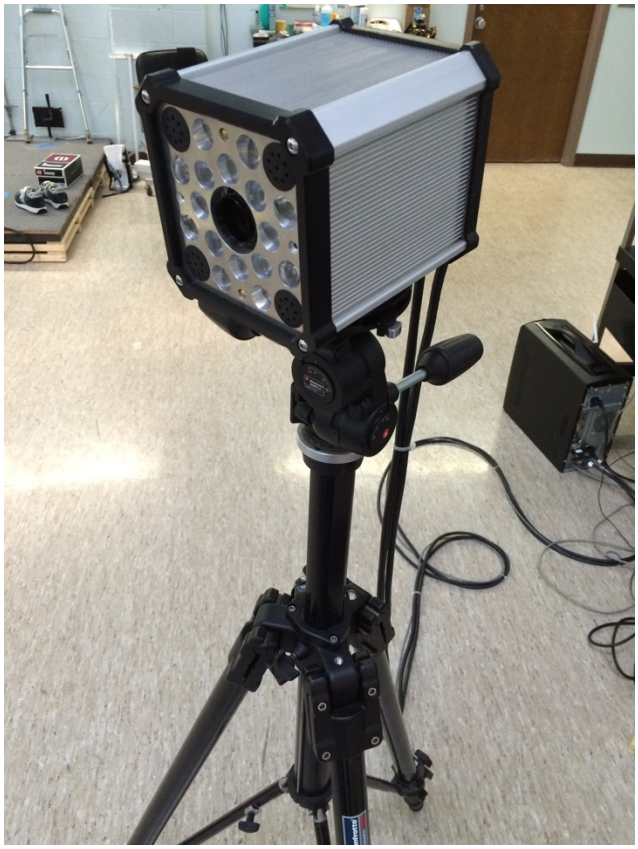


Figure 2.3 Single-camera system

Other:

- Retro reflective markers:
    - plates made of plastic (7cm / 7cm) (see Figure 2.5)
    - Manufacturer: Metria Innovation (Milwaukee, Wisconsin)
- “Wand” for placement of anatomical landmarks (see Figure 2.4)
- Measuring tape to get participants height

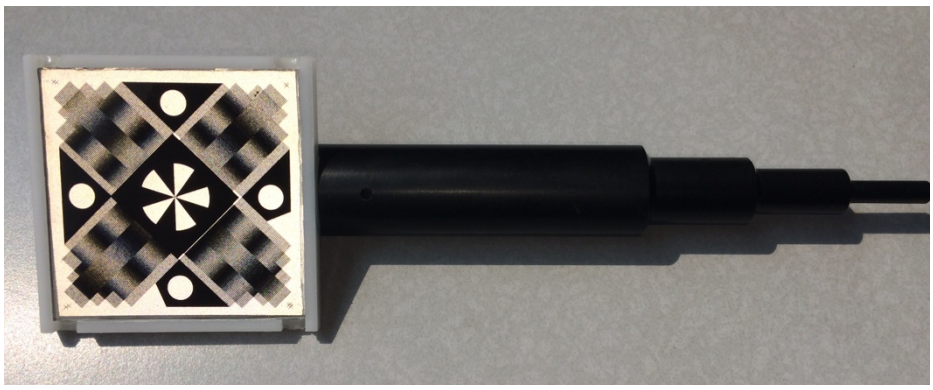


Figure 2.4 Wand for capturing ALs

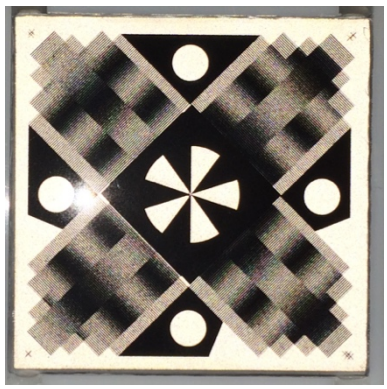


Figure 2.5 Retro-reflective marker

2.3 Measurement Protocol

Gait analyses were performed on each subject on two different days to allow analysis of day-to-day differences. Two independent testers collected data. Tester 1 was a trained physical therapist. I recorded the second data set (tester 2). This allows a comparison within-tester and between-testers. Firstly stance was recorded (Figure 2.6).

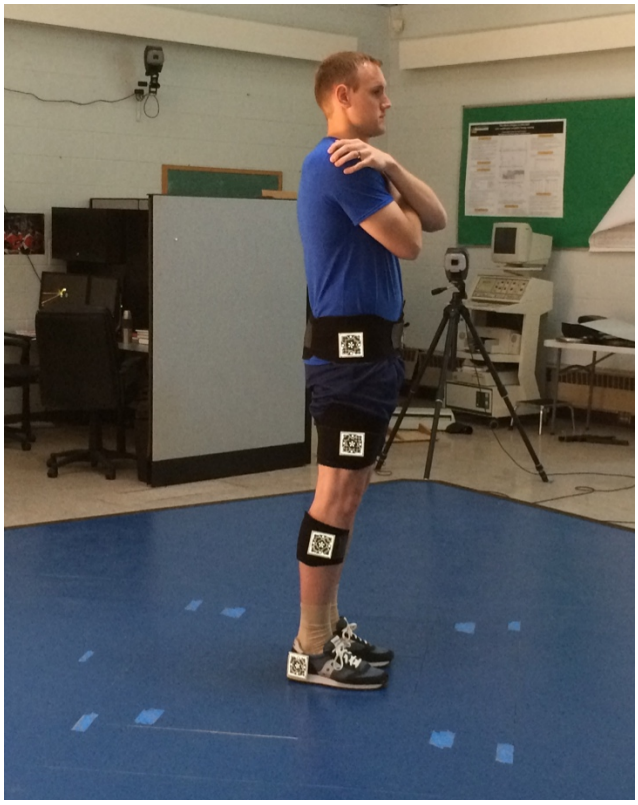


Figure 2.6 Stance trial

Subjects were instructed to perform a series of static (stance trial) and dynamic calibration trials to estimate the location of hip joint center (HJC), knee joint axis (KJA) and functional flexion / extension axes of the right knee.

Locating Anatomical Landmarks

In order to get kinematic data, anatomical landmarks (ALs) were located on the pelvis and the right lower extremity. The procedure of palpating the ALs was done by both testers and is shown exemplarily in Figure 2.8 and Figure 2.7. In total 13 landmarks were registered for each subject.

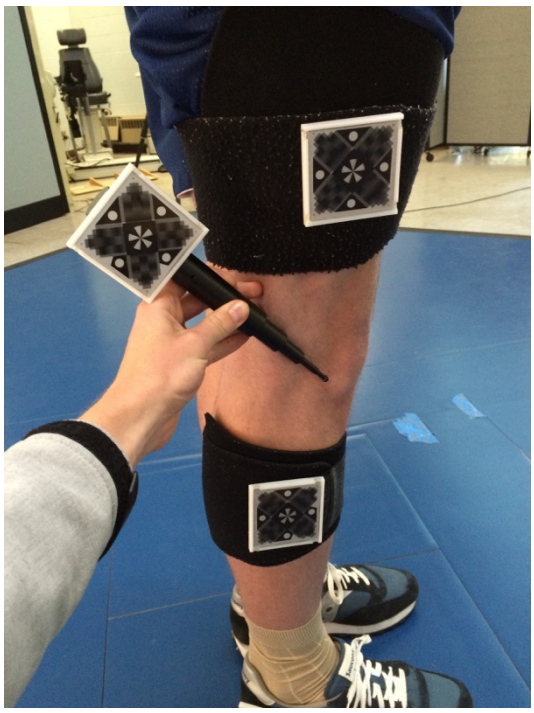


Figure 2.7 AL placement

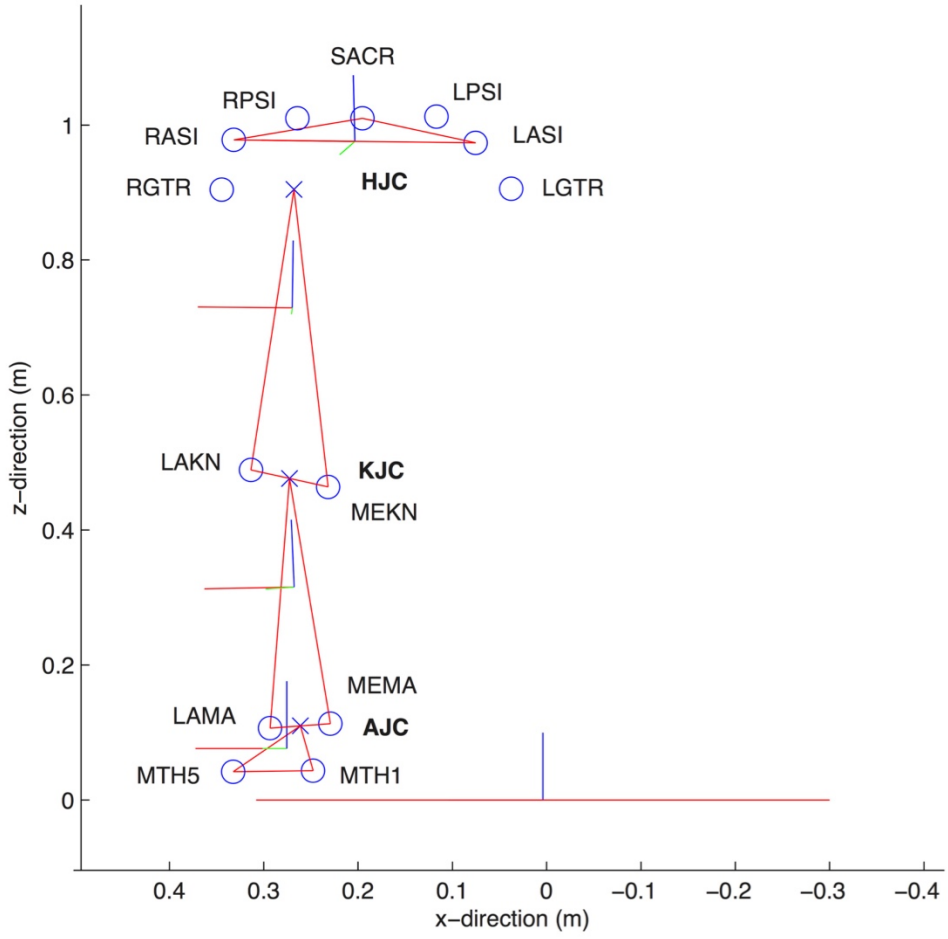


Figure 2.8 Anatomical landmarks

Pelvis:	SACR	Sacrum
	RPSI	Right Posterior Superior Iliac
	LPSI	Light Posterior Superior Iliac
	RASI	Right Anterior Superior Iliac
	LASI	Left Anterior Superior Iliac
Hip:	RGTR	Right Greater Trochanter
	LGTR	Left Greater Trochanter
Knee:	LAKN	Lateral Knee
	MEKN	Medial Knee
Ankle:	LAMA	Lateral Malleolus
	MEMA	Medial Malleolus
Foot:	MTH1	Metatarsal 1
	MTH5	Metatarsal 5

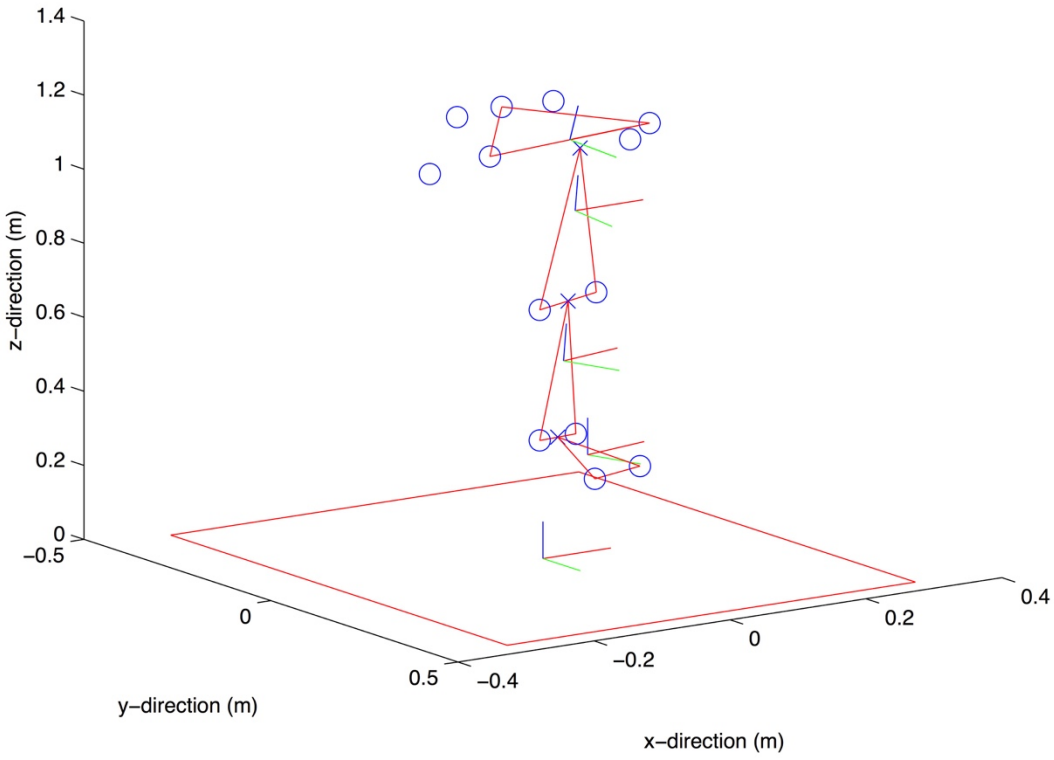


Figure 2.9 Overview of AL placement

Collecting Gait Data

During each session, subjects walked at a self-selected but controlled pace across the measurement platform. A starting point was set to establish a consistent footfall on the force place (middle of capture volume) and a constant walking speed. A minimum of 10 walking trials were collected containing successful strides within the capture volume.

2.4 Estimation of Joint Centers

The existing code only offered kinematic and kinetic calculations based on a single approach of estimating joint centers. In order to proof which method of estimating a joint center is the most reliable, I implemented additional methods for determining the location of HJC, KJC and AJC as can be seen in .

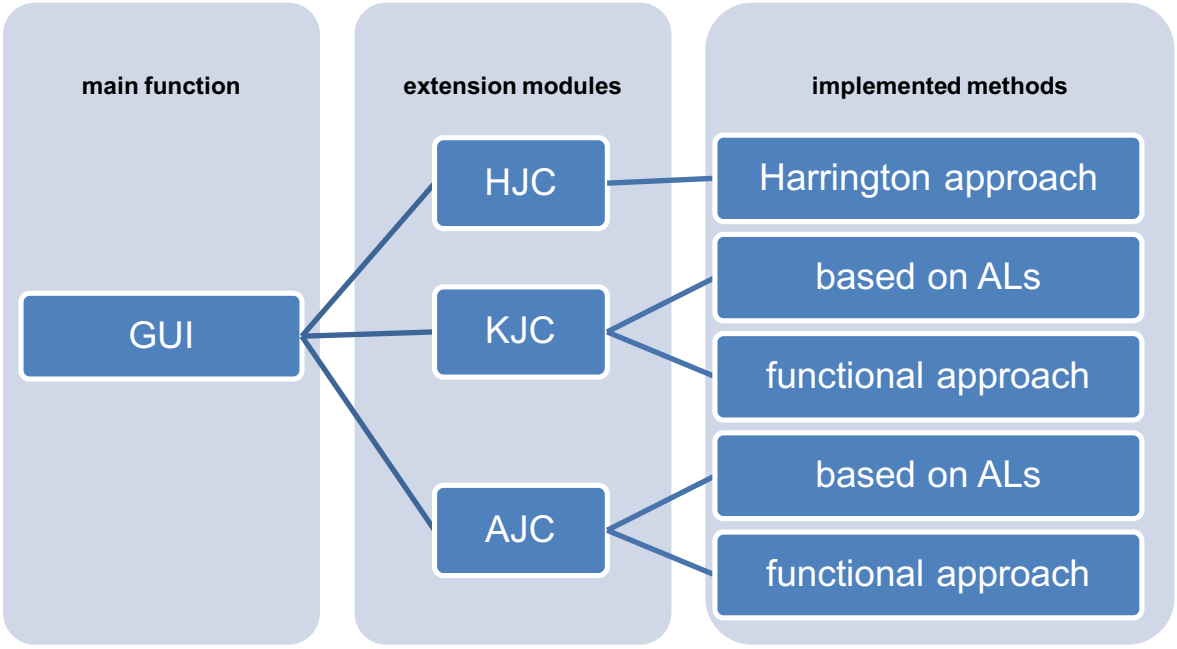


Figure 2.10 Different methods of estimation joint-centers

We decided to use the following method to estimate the hip joint center (HJC):

1. **Harrington / Bell method**
   This approach uses the empiric work of Bell, who looked at the relationship between palpable anatomical landmarks on the pelvis and the position of the HJC using x-ray (Bell, Brand, & Pedersen, 1989).

We looked at two different ways to estimate the knee joint center (KJC):

1. **Based on anatomical landmarks (ALs):**
   This method is based on the two most prominent anatomical landmarks on the knee: The medial and lateral epicondyles, abbreviated MEKN and LAKN, the midpoint between these two points represent the KJC.
2. **Functional approach:**
   This method relies on a specific movement, which has to be performed by the subject during the measurement. In this case the movement is a simple knee flexion and extension. The algorithm in the code analyzes the relative movement between the thigh- and the shank segment and fits an axis at the point of rotation (Ehrig, Taylor, Duda, & Heller, 2007).

Consequently two ways to estimate the ankle joint center (AJC) were looked at:

1. **Based on anatomical landmarks (ALs):**
   This method is based on the two most prominent anatomical landmarks on the ankle: The medial and lateral malleoli, abbreviated MEMA and LAMA, the midpoint between these two points represent the AJC.
2. **Functional approach:**
   Dr. O'Connor introduced this new method. Here the rotational axes of the knee is taken and fitted at the AJC, which was calculated as described above. The idea behind this is to remove cross talk between the frontal and the sagittal plane.

2.5 Data Processing

Data were collected with the single camera system with a sampling rate of 60Hz. The data were filtered using a fourth order Butterworth low pass filter with the filter cutoff set at 8Hz.

For each of the three calibration methods anatomical coordinate systems (ACS) were developed corresponding to the selected calibration process (anatomical ankle, anatomical knee, functional knee). So the three different combinations of subject calibration were applied to the data in order to generate three different anatomical coordinate system and thus three different data sets, which are compared in the discussion section.

For each individual movement trial stance phase was determined used a custom written algorithm (see Appendix A). From those data joint kinematics were generated at the hip, the knee and the ankle in 3D in the sagittal, frontal and traverse planes.

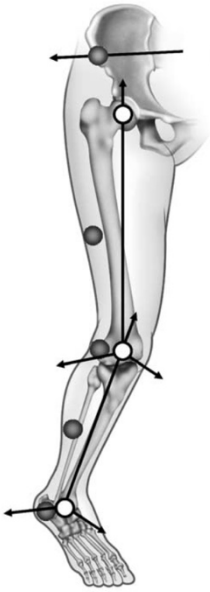


Figure 2.11 Establishing ACS (Cappozzo et al., 2005)

Joint angles were calculated using a joint coordinate system (JCS) (see Figure 2.11) approach in compliance with a Cardan angle rotation sequence (Grood & Suntay, 1983).

In order to assess the relationship between the two testers on one day (intertester reliability) and the relationship of one tester between days (intratester reliability), the coefficient of determination (r^2) was calculated. Initial contact (IC) and range of motion (ROM) of the hip, knee and ankle joint are reported in all three planes.

3 Results

Figure 3.1, Figure 3.2 and Figure 3.3 represent the calculated joint angles of a randomly chosen subject in order to illustrate the ROM across the frontal, the sagittal and the transversal plane.

3.1 Joint Angles

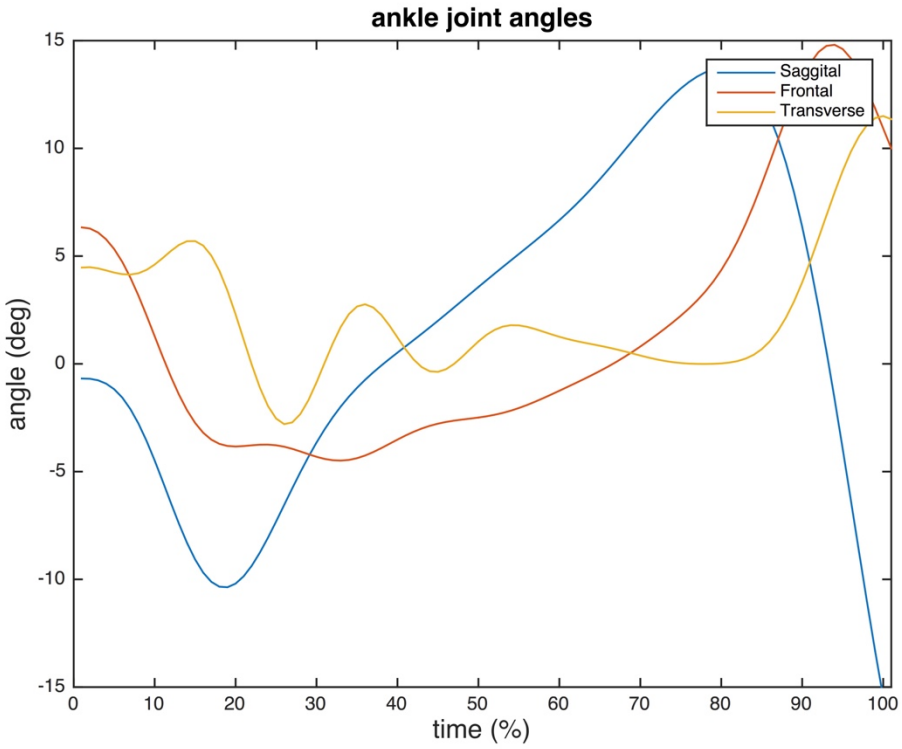


Figure 3.1 Ankle joint angles of subject 5

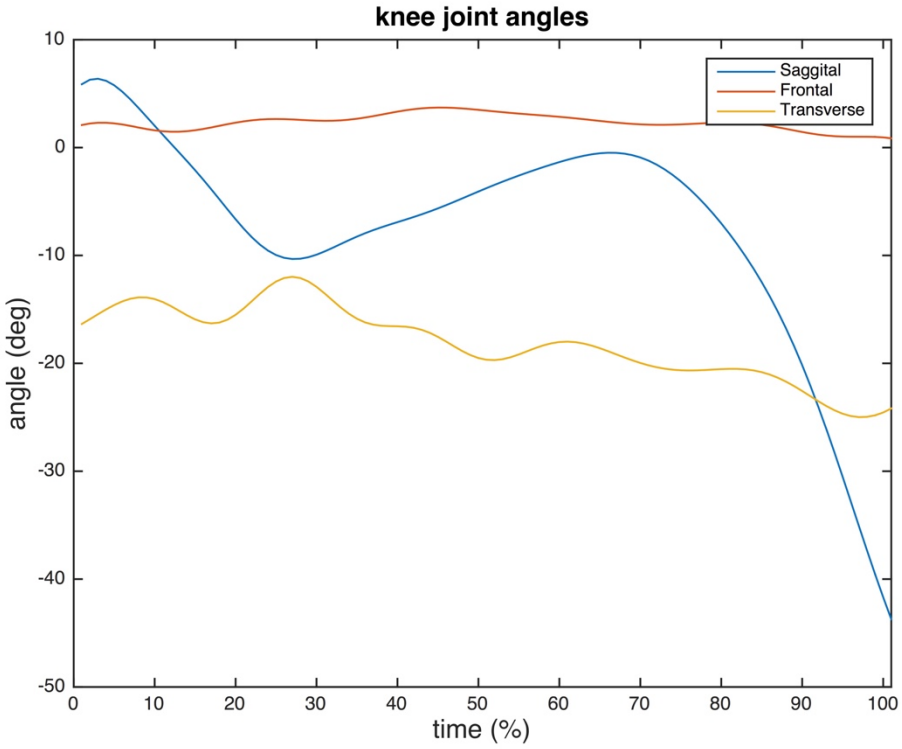


Figure 3.2 Knee joint angles of subject 5

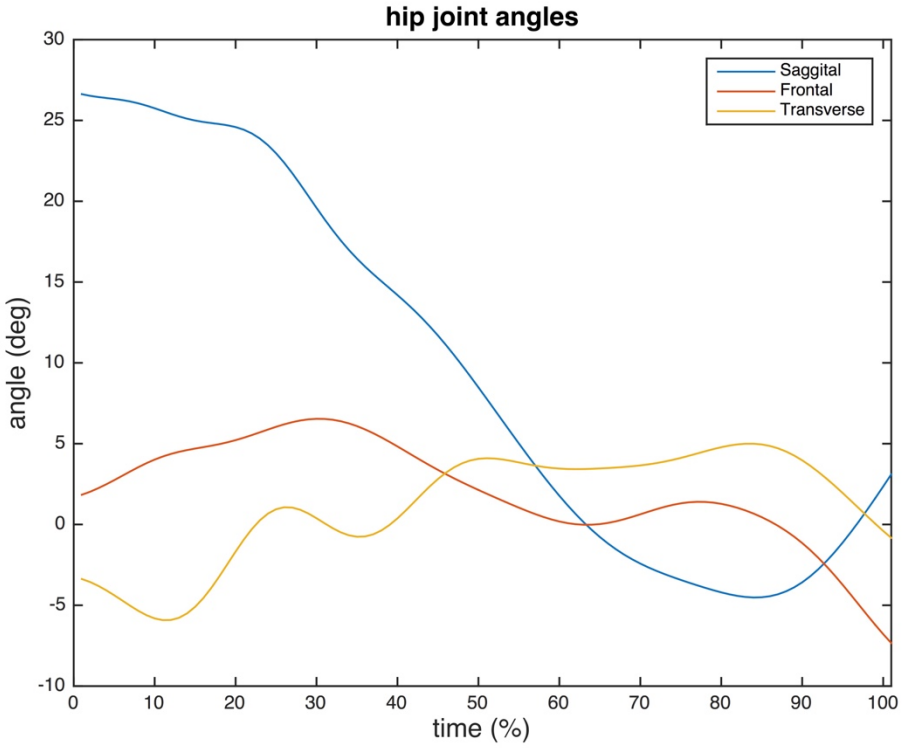


Figure 3.3 Hip joint angles of subject 5

3.2 Correlations

Range of motion (ROM) variables were more reliable in general than initial contact (IC) angles. Transverse angles were generally less reliable than the other planes. The functional approach improved reliability of the transverse plane contact angles.

Table 3.1 Comparison T1 between days.

		Sagital		Frontal		Transverse	
		IC	ROM	IC	ROM	IC	ROM
Hip	KAL AAL	0,692	0,827	0,462	0,489	0,540	-0,332
	KFC AAL	0,693	0,828	0,458	0,489	0,502	-0,320
	KFC AKN	0,693	0,828	0,458	0,489	0,502	-0,320
Knee	KAL AAL	0,953	0,920	0,900	0,749	0,689	0,905
	KFC AAL	0,946	0,908	0,923	0,362	0,759	0,904
	KFC AKN	0,946	0,908	0,923	0,362	0,766	0,904
Ankle	KAL AAL	0,502	0,809	0,728	0,825	-0,119	0,843
	KFC AAL	0,464	0,823	0,746	0,829	-0,134	0,840
	KFC AKN	0,211	0,821	0,793	0,818	0,842	0,843

Table 3.2 Comparison T2 between days

		Sagital		Frontal		Transverse	
		IC	ROM	IC	ROM	IC	ROM
Hip	KAL AAL	0,484	0,819	0,798	0,510	0,232	-0,197
	KFC AAL	0,543	0,818	0,832	0,470	0,522	-0,205
	KFC AKN	0,543	0,818	0,832	0,470	0,522	-0,205
Knee	KAL AAL	0,905	0,919	0,786	0,408	0,728	0,897
	KFC AAL	0,909	0,918	0,781	0,374	0,731	0,910
	KFC AKN	0,909	0,918	0,781	0,374	0,786	0,909
Ankle	KAL AAL	0,532	0,727	0,742	0,814	0,131	0,842
	KFC AAL	0,429	0,727	0,734	0,813	0,122	0,839
	KFC AKN	0,288	0,795	0,780	0,820	0,839	0,850

Table 3.3 Inter-tester comparison on D1

		Sagital		Frontal		Transverse	
		IC	ROM	IC	ROM	IC	ROM
Hip	KAL AAL	0,827	0,999	0,615	0,954	0,815	0,918
	KFC AAL	0,800	0,999	0,619	0,956	0,952	0,915
	KFC AKN	0,800	0,999	0,619	0,956	0,952	0,915
Knee	KAL AAL	0,914	1,000	0,895	0,690	0,607	0,998
	KFC AAL	0,966	1,000	0,920	0,995	0,754	0,999
	KFC AKN	0,966	1,000	0,920	0,995	0,999	0,999
Ankle	KAL AAL	0,978	0,985	0,986	0,997	0,566	0,999
	KFC AAL	0,963	0,985	0,983	0,997	0,551	0,999
	KFC AKN	0,991	0,994	0,995	0,995	0,939	0,9998

Table 3.4 Inter-tester comparison on D2

		Sagital		Frontal		Transverse	
		IC	ROM	IC	ROM	IC	ROM
Hip	KAL AAL	0,522	1,000	0,731	0,967	0,648	0,895
	KFC AAL	0,561	1,000	0,751	0,959	0,921	0,900
	KFC AKN	0,561	1,000	0,751	0,959	0,921	0,900
Knee	KAL AAL	0,849	0,999	0,950	0,765	0,704	0,993
	KFC AAL	0,934	1,000	0,946	0,981	0,955	0,997
	KFC AKN	0,934	1,000	0,946	0,981	0,999	0,997
Ankle	KAL AAL	0,945	0,959	0,980	0,985	0,819	0,998
	KFC AAL	0,960	0,954	0,994	0,985	0,816	0,999
	KFC AKN	0,989	0,939	0,990	1,000	0,949	0,999

4 Discussion

In general, the implemented method of estimating the knee joint center using a functional approach appears to produce a more repeatable representation of the knee joint center. This results in significant improvements in the repeatability of clinical output variables. The most positive result is the between tester comparison. It could be shown that the values of correlation are consistently above 0.9 throughout most variables of interest. The implementation of the functional knee method especially improved the reliability of the initial contact angle in the hip at touchdown.

Within a tester across days the reliabilities were generally relatively low. Reasons for such low between-day repeatability of all plane angles included skin movement artefact and marker re-application, coupled with the natural variability of the walking pattern of the subject. (Besier, Sturnieks, Alderson, & Lloyd, 2003).

However, the comparison between testers on the same day represents the exact same walking trial acquired with different calibration points. This comparison only shows the differences between testers. Here a positive result could be shown as mentioned above.

The assumption that tester 1 (T1) who is a trained physical therapist would produce data with a higher grade of repeatability did not prove to be correct. The correlation values of tester 2 (T2) are surprisingly similar. These results indicate that the clinical introduction of this system might be further facilitated since no extensive training of the observer is necessary.

4.1 Limitations

One limitation of the single camera system is the relatively small capture volume. This results in capturing only a single step within the gait cycle. Perhaps a continuous measurement would improve the reliability of the recorded movement data, this could be overcome by the use of a treadmill which is placed within the capture volume.

Furthermore, the subjects in this study were young and healthy, with minimal body fat, which would improve the ability to locate ALs, particularly on the pelvis. In subject populations where palpation of pelvis ALs becomes difficult, the functional method would be expected to produce more repeatable gait data than the AL method between testing sessions. The functional approach might also produce more repeatable knee joint kinematics and kinetics than the AL model in subjects who have bony deformities of the knee joint, where location of the epicondyles. (Chiari et al., 2005)

4.2 Outlook

Based on the results I recommend the adaptation of the camera system in order to provide compatibility with various force plates used in clinics today.

Methods that need to be investigated further are an implementation of a functional approach of estimating the HJC. Using a functional approach for locating the HJC might increase the reliability of the system further.

Although original technical limitations in clinical gait analysis have been resolved by improvements in modern instrumentation, limitations are still present in the current data collection and measurement protocols. A newly developed protocol is proposed here, to provide a further step in developing a way of collecting data that is not prone to error. The implementation of this technology in a clinical environment will have a significant impact on the evaluation and treatment of gait dysfunction. Especially because of its user friendliness and the minimal technical equipment (a single camera on a stand, and a PC) that is needed to track human locomotion.

5 Project Report (Appendix I)

This section contains a detailed description of my work at the University of Wisconsin Milwaukee in collaboration with Dr. O'Connor.

5.1 Coding

Creating code for data analysis prior to collecting data helped to save valuable time and to avoid critical errors during data collection and was therefore essential to the overall project. After extensive literature research (see Appendix II) I was introduced to existing code written by Dr. O'Connor. This code had to be adapted to fit the needs of our project. Since the camera system could not read out analog data of the force plate at the time of the project the code had to be changed in a way that it would work without the force plate data. Not using analog data of a force-plate resulted in a trade-off: When force-data is available, kinematics and kinetics can be calculated. The lack of a force-plate allows the calculation of kinematics only.

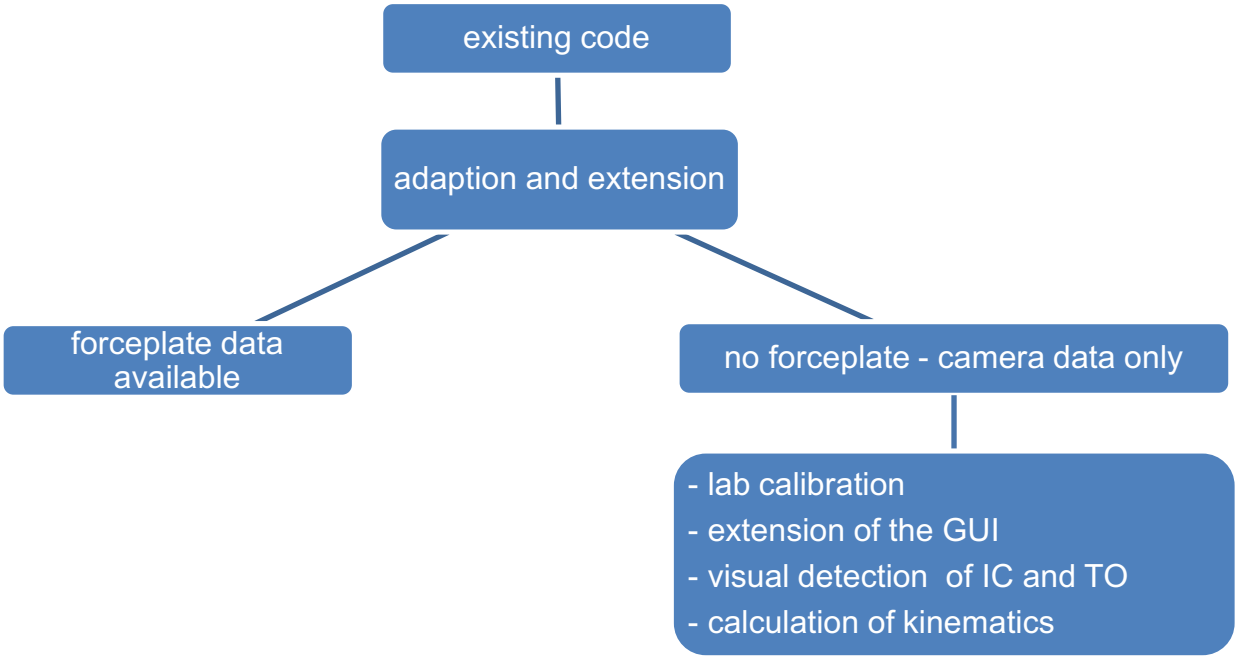


Figure 5.1 process of coding

I was further instructed to adapt and extend a costume written graphical user interface, which was handed to me by my supervisor. Based on his existing code I made changes to the GUI and to its sub-functions. These changes involved the adaption of an algorithm for a lab calibration using Gram-Schmidt orthogonalization, the extension of the GUI, the

visual detection of initial contact (IC) and toe-off (TO) and adaption in the process of calculation kinematics.

5.2 Graphical User Interface

The GUI represents the core of the program. I extended and improved the GUI so it was ready to be used prior to the actual data collection, which presented us with 2 major advantages:

- We could use the GUI to pre-process data during pilot testing, which saved valuable time and prevented errors during the actual measurement.
- The collected data could be processed during or shortly after actual data collections. This way we could check the data visually and rerun a measurement if necessary.

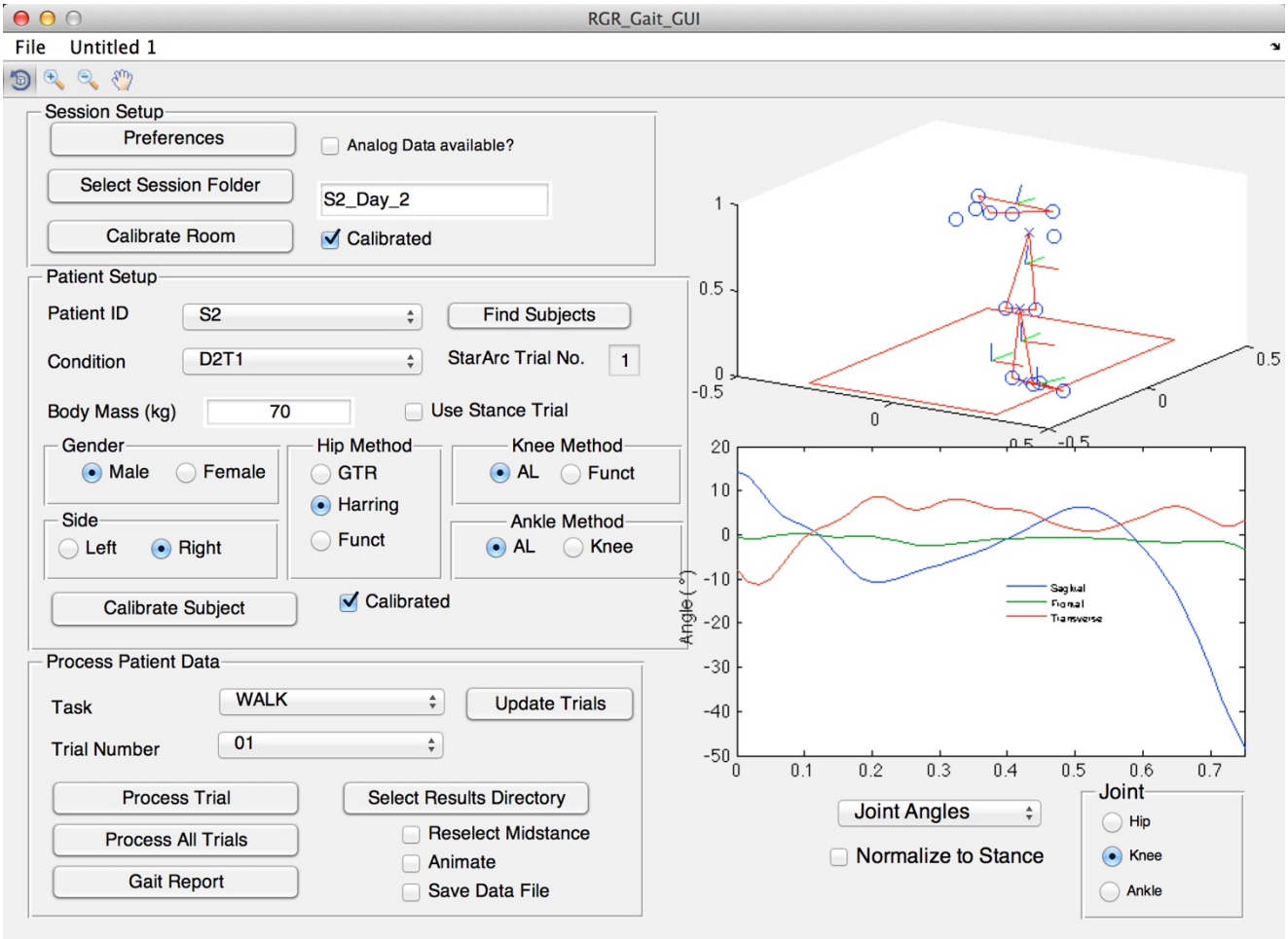


Figure 5.2 GUI (main program)

Session Setup

First the data had to be loaded by selecting a session folder. The calibration algorithm transforms the data from the camera coordinate system into the room coordinate system (GCS).

Patient Setup

This part allows the selection of the desired calculation methods for establishing the joint centers of hip, knee and ankle. After calibrating the subject a model of the selected subject is shown on the right-hand side to allow visual control of the data by the user.

Processing Patient Data

After processing the collected walking trials (n=10), the processed data can be viewed at the plot on the right-hand side. The data can be saved for post-processing and statistical analysis.

5.3 Detection of Gait Events

A new algorithm that uses the visual data of the single-camera system had to be implemented in order to detect initial contact and toe-off. In order to construct this algorithm I used previously collected data, which had had force information to validate the detection of gait events such as initial contact and toe off. The challenge was to detect these points without using the typical shape of the ground reaction force (blue line in Figure 5.3 and Figure 5.4). The red line is a dynamic threshold that ensures the correct detection of peaks within the data set.

The diagram below shows a data set where we compared the GRF to characteristic points on the turquoise line (position data of the foot). The first peak (red circle) prior to mid-stance (green circle) gives a fairly accurate representation of the point where the heel strikes the ground. The difference between the GRF IC and the visual IC is the range of a few frames (5 to 10) at a sampling rate of 60Hz.

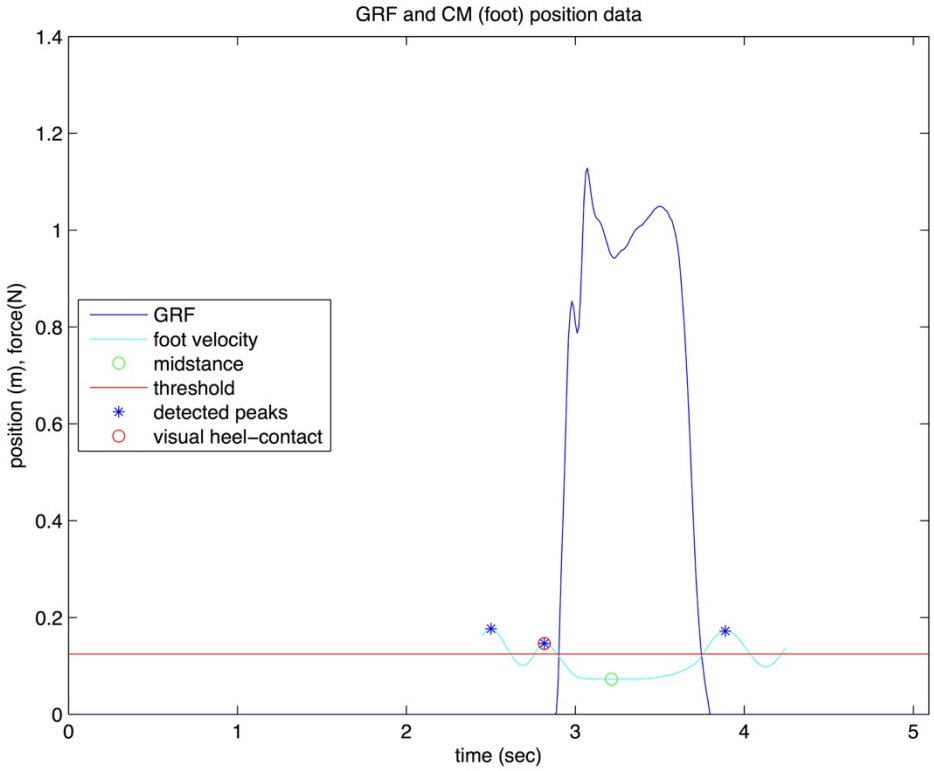


Figure 5.3 detection of initial contact

The diagram below shows a data set where we compared the GRF to characteristic points on the turquoise line (velocity data of the foot) in order to visually detect toe-off. The first peak (red circle) after mid-stance (green circle) gives a very accurate representation of the point where the foot leaves the ground. The difference between the GRF TO and the visual TO is the range of a 0 to 2 frames at a sampling rate of 60Hz.

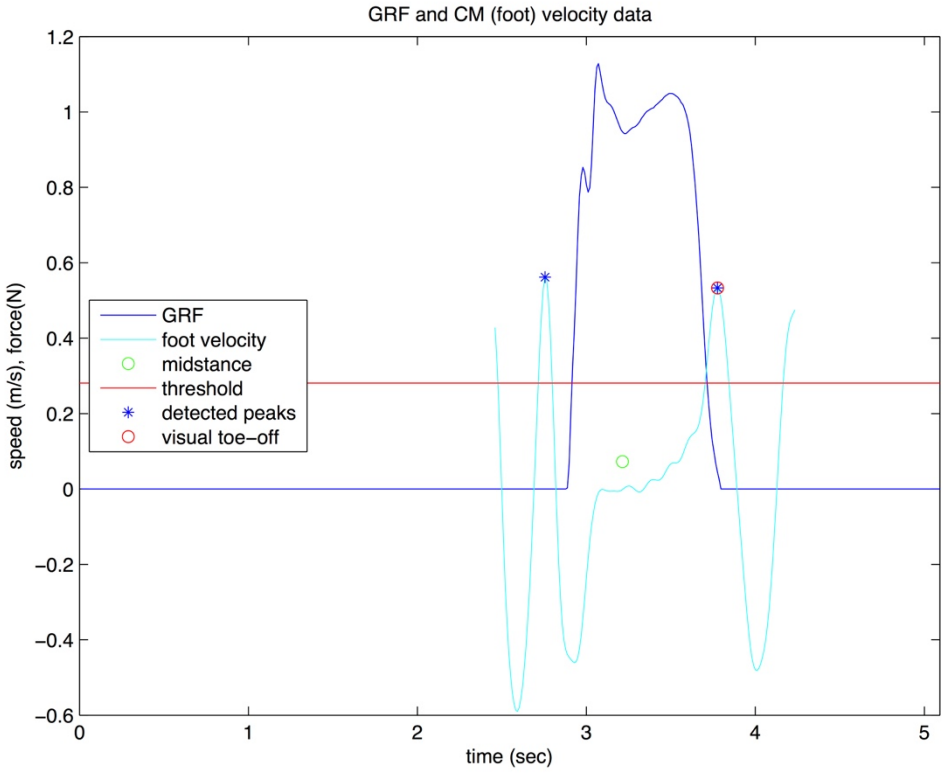


Figure 5.4 detection of toe-off

6 Literature Review (Appendix II)

This section provides background information on clinical gait analysis and on the instrumentation and methods used in order to analyze human motion.

6.1 Clinical Gait Analysis

Gait (walking and running) is the most common activity performed by humans, and impairment of gait can have a profound impact on a person's quality of life. Consequently, it has a major effect on society since movement-related health problems are becoming increasingly prevalent.

Gait analysis is used for two very different purposes: to aid directly in treatment of individual patients and to improve our understanding of gait through research.

Assessment of gait function is a critical component of the treatment of patients with orthopedic, neuromuscular and cardiopulmonary conditions. These assessments are used to guide treatment decisions and monitor progress. Specifically, clinical gait analysis can be used to achieve one of four goals (Kirtley, 2006):

- Diagnosis between diseases
- Assessment of the severity of the disease
- Monitoring of progress of rehabilitation
- Prediction and monitoring of the outcome of surgical interventions

There are a number of different methods used to accomplish the analysis of human locomotion. Naturally is has to be considered how much time and money can be invested in monitoring of a person's gait pattern. Consequently clinical gait analysis may be conducted observationally or by 3-D motion capture.

Observational Gait Analysis

Information obtained from Observational gait analysis (OGA) is used to identify specific impairments and to establish a treatment plan. Many clinicians include the observation of a subject's gait as part of their clinical examination. OGA is one of the most frequently employed assessment tools in clinical practice. Observational gait analysis is a rather easy and cost-effective method of assessing walking disorders, it is however only a moderately reliable technique for investigating kinematic gait deviations (Krebs, Edelstein, & Fishman, 1985). The assessment of walking disorders is entirely subjective and the quality of the analysis depends on the skill of the person performing it (Levine et al., 2012).

Major disadvantages are that it is difficult or impossible to see motion across planes, and OGA requires a great deal of training and practice for proficiency. For gross movement problems, OGA is often quite appropriate, but it is virtually impossible to see small deviations with the unaided eye. Slow motion digital video can be used to supplement simple observation, but the results are still often equivocal. Although the reliability of OGA can be improved when video recordings are used, this approach limits the ability to assess the three-dimensional aspects of gait.

Instrumented Gait Analysis

Instrumented, Computerized Gait Analysis gives the clinician objective three-dimensional information with good reliability and validity, and thus overcomes the major limitations of OGA. Instrumented CGA also makes "invisible" information - such as forces, moments, and muscle activity - readily apparent after data processing. Information obtained from instrumented gait analysis can be used by health care professionals to identify specific impairments and to establish treatment plans (Deluca, 1991). As a result sound clinical decision making depends on the reliable assessment of gait function (Levine et al., 2012). The estimation of different sources of error is therefore crucial for assessing the reliability of human gait analysis. As a practical matter, instrumented CGA is probably most valuable when there are complex gait deviations that are difficult or impossible to see clearly with the unaided eye. But, as the cost of gait lab equipment continues to steadily drop, we should begin to see more and more clinicians with access to objective gait data to supplement and refine their treatment recommendations.

7 Further Material (Appendix III)

7.1 IRB Certificate

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COURSEWORK TRANSCRIPT REPORT**

** NOTE: Scores on this Transcript Report reflect the most current quiz completions, including quizzes on optional (supplemental) elements of the course. See list below for details. See separate Requirements Report for the reported scores at the time all requirements for the course were met.

- **Name:** Klaus Weissenboeck (ID: 4795373)
- **Email:** weissenb@uwm.edu
- **Institution Affiliation:** University of Wisconsin - Milwaukee (ID: 1195)
- **Institution Unit:** Kinesiology
- **Phone:** 4147366098

- **Curriculum Group:** IRB-Biomedical Researchers
- **Course Learner Group:** Same as Curriculum Group
- **Stage:** Stage 1 - Basic Course
- **Description:** Choose this group to satisfy CITI training requirements for Investigators and staff involved primarily in biomedical research with human subjects.

- **Report ID:** 15841144
- **Report Date:** 04/24/2015
- **Current Score**:** 93

REQUIRED, ELECTIVE, AND SUPPLEMENTAL MODULES	MOST RECENT	SCORE
History and Ethics of Human Subjects Research (ID:498)	04/21/15	7/7 (100%)
Students in Research (ID:1321)	04/21/15	9/10 (90%)
Informed Consent (ID:3)	04/21/15	4/5 (80%)
Social and Behavioral Research (SBR) for Biomedical Researchers (ID:4)	04/21/15	4/4 (100%)
Belmont Report and CITI Course Introduction (ID:1127)	04/21/15	3/3 (100%)
Records-Based Research (ID:5)	04/23/15	3/3 (100%)
Genetic Research in Human Populations (ID:6)	04/23/15	2/2 (100%)
Vulnerable Subjects - Research Involving Prisoners (ID:8)	04/24/15	4/4 (100%)
Vulnerable Subjects - Research Involving Children (ID:9)	04/24/15	3/3 (100%)
Vulnerable Subjects - Research Involving Pregnant Women, Human Fetuses, and Neonates (ID:10)	04/24/15	3/3 (100%)
FDA-Regulated Research (ID:12)	04/24/15	4/5 (80%)
International Studies (ID:971)	04/24/15	3/3 (100%)
Vulnerable Subjects - Research Involving Workers/Employees (ID:483)	04/24/15	4/4 (100%)
Conflicts of Interest in Research Involving Human Subjects (ID:488)	04/24/15	3/5 (60%)
Avoiding Group Harms - U.S. Research Perspectives (ID:14080)	04/24/15	3/3 (100%)
Basic Institutional Review Board (IRB) Regulations and Review Process (ID:2)	04/21/15	5/5 (100%)
Populations in Research Requiring Additional Considerations and/or Protections (ID:16680)	04/24/15	5/5 (100%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

CITI Program
Email: citisupport@miami.edu
Phone: 305-243-7970
Web: https://www.citiprogram.org

Index of Figures

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