

# Lower-Limb Motion Estimation

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Kinematic Modelling and Estimation of the Gait using Cameras  
and an IMU



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## Terms of Reference

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### **Title**

Lower-Limb Motion Estimation - Kinematic Modelling and Estimation of the Gait using Cameras and an IMU

### **Description**

Recent breakthroughs in the field of artificial intelligence has invigorated the pursuit of humanoid robots. Unfortunately, modern bipedal robots lack the elegance of motion and fluidity observed in nature. Perhaps then a modern take on the lower limb kinematics of humans could provide insight to the field of bio-inspired robotics. By using modern cameras with minimal volume and accurate sensors, data capture systems can be transferred onto the subjects in question. This methodology allows for a much larger spectrum of motion capture and can greatly improve our understanding of movement in the unconstrained real world.

### **Deliverables**

The following items have been identified as critical deliverables for the project:

- Functional harness to hold data capture equipment
- Estimation and fusion algorithm to process captured data
- Kinematic model of the human lower-limbs

### **Skills and Requirements**

Mechanical Design, Electrical Design, Programming and Modelling.

### **Area**

Computer Vision, Sensors, Biomechanics and Bio-inspired Robotics.

## Declaration

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2. I have used the IEEE convention for citation and referencing. Each contribution to, and quotation in, this report from the work(s) of other people has been attributed, and has been cited and referenced.
3. This report is my own work.
4. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as their own work or part thereof.

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**October 14, 2017**

## Acknowledgements

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I would like to thank some people...

## Abstract

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This research aims to extend the work completed by the Mechatronics Lab at the University of Cape town. This research studied the use of subject borne cameras to analyse, model and estimate the kinematic motion of a cheetah tail. Computer vision has progressed significantly within the last few years and studying the motion of animals with subject borne cameras allow unconstrained environments.

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# Glossary

Abbreviations listed here are used throughout the document.

- DOF - Degrees Of freedom
- GPHS - GoPro Hero Session
- MEMS - Micro Electromechanical System

# Chapter 1

## Introduction

### 1.1 Background to the study

Human motion capture systems are often very costly and confine the capture area to a certain confined space. These limitations prevent us from understanding bipedal motion in complex environments, knowledge that proves to be critical in the development of humanoid robotics. These limitations can be seen in [1] where 8 cameras and stereo vision was used to recreate a 3D model of a walking person.

Recent work [2] completed by the Mechatronics Lab at the University of Cape Town showed data capture with subject-borne cameras and sensors can be used to better understand unconstrained movement in a natural environment. The presented work showed the successful kinematic modelling of a cheetah (*Acinonyx jubatus*) tail whilst running freely. This work was inspired by [3] where the importance of a tail for manoeuvrability was demonstrated.

The field of bio-inspired robotics aims to understand various natural phenomena and incorporate these techniques into the design of modern robotics.

This project seems to be somewhat novel as no research modelling the human gait with subject borne cameras was available at the time of writing.

### 1.2 Objectives of this study

Depth imagery in the field of human motion capture has been extensively reviewed in [4], where the lack of data from complex movements in different environments is listed as a challenge. This reaffirms the difficulty stated in the previous section. Solely relying on motion sensors to understand the gait has been reviewed by [5]. Although this approach was found to be accurate for external environments it has limitation with respect to cost and sensor disturbance. From these reviews it is clear that a middle ground must exist that can combine the strengths of the approaches to provide a holistic solution.

This research project aims to show that subject-borne sensors, primarily a combination of cameras and IMUs, can provide researchers in the field of biomechanics and bio-inspired robotics with extensive datasets to better understand and model the bipedal motion of humans.

## **1.3 Scope and Limitations**

The scope of this research is to model and estimate the human lower limbs during a flat ground run. This is the first logical step in the iterative design process to eventually understand movement in complex environments.

The research presented herein does not seek to push the boundaries of modern sensor technology, nor does it wish to re-imagine understood and accepted models of natural phenomena. Instead, a methodology is proposed that brings together systems from exciting disciplines of research such that richer datasets can be generated and studied.

It should therefore be understood that the following work serves as a proof of concept and not as a final design of a motion capture system.

## **1.4 Plan of Development**

The following chapter contains an extensive literature review where various methods of modelling and verifying the human gait has been discussed. There are also sections dedicated to subject borne data capture, computer vision, inertial measurement units (motion sensors), humanoid robotics and mathematical modelling.

This is followed by a chapter titled methodology that presents the the planning and ideation of the thesis. It serves as a link between the theoretical work presented in the literature review and the engineering approach and application detailed in the chapters that follow it. It lays out a plan and shows how engineering specifications were generated from a generally defined problem.

The final three chapters that make up the body of this report are titled "Designing the Data Capture System", "Processing the Captured Data" and "Data Fusion and State Estimation" in order of appearance. True to their title they present the process followed to complete the major milestones of the project.

In closing a chapter is dedicated to presenting and discussing the results obtained, followed by the final chapter that draws conclusions from the presented work and makes recommendations on future work.

# Chapter 2

## Literature Review

This section reviews various academic sources related to the methodology proposed.

### 2.1 Introduction

This research project brings together various disciplines of research. By combining techniques from computer vision, sensors and data fusion we can design and develop new way of capturing human gait data.

### 2.2 Human Motion and Gait

The human gait is well understood and has been studied in detail as it is a fundamental part of human mobility. It is one of the first skills developed in infancy and its importance for healthy development, as outlined by Adolph et al. [6], cannot be understated. Walking and running are also critical factors in transportation and geographical movement of people and goods in developing countries where public transport is underdeveloped and private transport not within the means of the populous. Finally walking and running as exercise has proven benefits as shown in [7] (general health) and [8] (mental health).

There is thus clear evidence that the human gait has earned its right as a field of study in academia.

### 2.3 Computer Vision

While the previous section answers "why" understanding the human gait is important, the following sections will explain fields that contribute to the question of "how" the gait is studied.

Computer vision is a field borne from image processing and artificial intelligence that seeks to replicate the ability of the human visual system.

### 2.3.1 Computer Vision in robotics

### 2.3.2 New Perspectives from Animal Borne Cameras

In large this researched project was inspired by work done in the Mechatronics Lab at the University of Cape Town. In 2017, Patel et al. [2] showed that using animal borne cameras and motion sensors, the tail kinematics of the cheetah (*Acinonyx Jubatus*) could be tracked. Patel's work was partly inspired by Kane et al. [9] where falcon (*Falco Peregrinus*) borne cameras were used to better understand airborne pursuit of prey.

Further work completed by Pearson et al. [10] showed that cameras mounted to dolphins (*Lagenorhynchus obscurus*) could provide insight into the their movement, social and foraging strategies. These examples show the promise that animal borne

### 2.3.3 Human Motion Analysis Using Computer Vision

## 2.4 Inertial Measurement Units

IMU's are a staple of electrical engineering as applied to dynamic systems. These sensors give us insight as to how an object is moving in space by providing data relating to orientation and acceleration of said system. These data points are created by electronically interpreting signals generated by micro-electromechanical system (MEMS). Modern smartphones have built in IMU's that are not only accurate [11], but also easy to interface with due to the open source nature of the Android operating system [12].

Generally IMUs contain the following subsystems:

- Accelerometer
- Gyroscope
- Magnetometer
- Barometer
- Temperature

**Accelerometers** provide linear acceleration data; these accelerations may be constant (eg. gravity) or changing (eg. relative motion). In smartphones they are usually based on MEMS that use

**Gyroscope**

**Magnetometer**

**Barometer**

**Temperature**

### **2.4.1 Inertial Measurement Units in robotics**

### **2.4.2 Human Motion Analysis Using Inertial Measurement Units**

## **2.5 Mathematical Modelling**

The binding element presented in this work is the underlying mathematics

### **2.5.1 math model of the human gait**

### **2.5.2 linear kinematics**

### **2.5.3 rotational matrices**

### **2.5.4 KF and EKF**

The Kalman filter is a mathematical used to estimate

## **2.6 Observing Natural Solutions for Robotic Shortcomings**

Naturally the question arises: why would we want to better understand the dynamics of animals? A persistent problem in the field of modern robotics is that of mobility; robots struggle to navigate real world surfaces and obstacles. Work by Patel et al. [13] shows how we can look towards nature for inspiration to solve this mobility problem.

This follows the central philosophy of bio-inspired robotics as defined by

As demonstrated by various prototype robots built by Boston Dynamics bipedal robots are severely limited in manoeuvrability when compared to

## **2.7 conclusion**

# Chapter 3

## Methodology

To ensure the success of this project a basic plan of action was created. The following diagram shows the critical phases of the project.

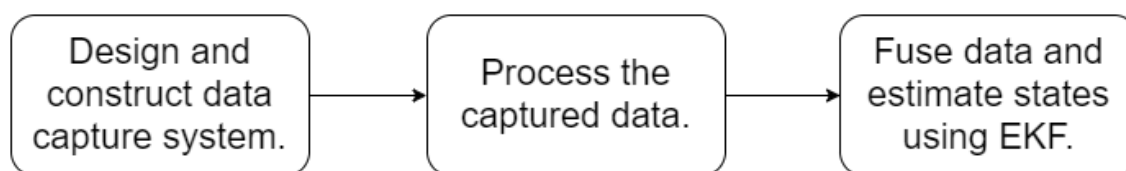


Figure 3.1: Diagram showing the progression and dependence of the major stages of this project

Due to the availability of equipment, financial limitations and time

### 3.1 System Design

This section is dedicated to defining and understanding the specifications of the data capture system. The system will consist of 4 cameras and an IMU mounted to the torso of the subject. the cameras will record the legs of the subject while the IMU will log inertial data from the body of the subject.

Due to the availability of equipment provided by the Mechatronics Lab the following equipment was chosen as the main components to use in the system:

Item	Selected Equipment	From
Camera	4 GoPro Hero Session Cameras	[14]
IMU	1 Sony Xperia Z3 Compact	[15]
Chest Mount	1 Action Mount Chest Mount	[16]

Table 3.1: The main components used.

The specifications of this data capture system has been defined as:



- Stereo housing to hold the cameras.
- Chest mount to hold the cameras and IMU.
- 
- 

## **3.2 Modelling the Lower Limbs**

## **3.3 Experimental Details**

The data was captured during a short

## **3.4 Limitations**

# Chapter 4

## Designing the Data Capture System

To obtain data for the Extended Kalman Filter, a data-capture system needed to be designed. Since the data sources have been identified as multiple video sources and a 9-DOF IMU.

### 4.1 Camera Mount Design

### 4.2 Designing the Body Harness

sdfgsdfgsdfg

adsfasdfsdg

sdfgsdfgdsf

sdfgdsfgdsfg

### 4.3 Vision Calibration

matlab stereo camera calibration software 1. calibrate the cameras 2. get data from the recordings

took some vids

made matlab script to isolate frames in vids

put frames into stereo video camera calibrator

winning at life



Figure 4.1: GoPro Chesty camera mount from [17]

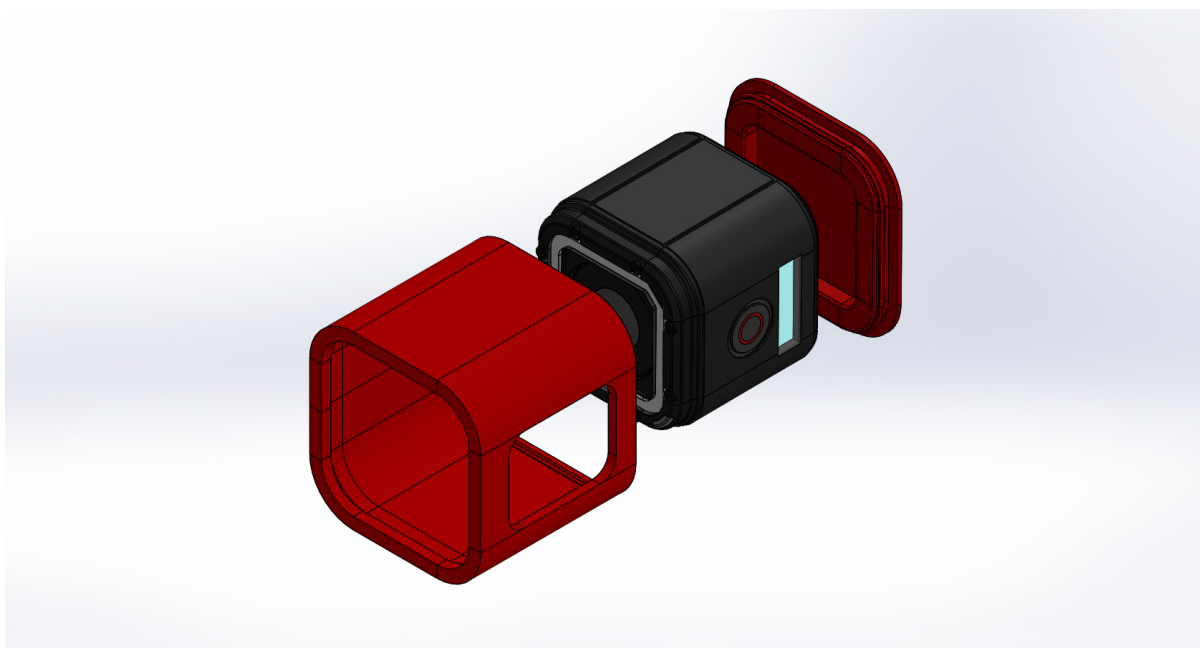


Figure 4.2: Solidworks model of the GoPros Hero 4 Session

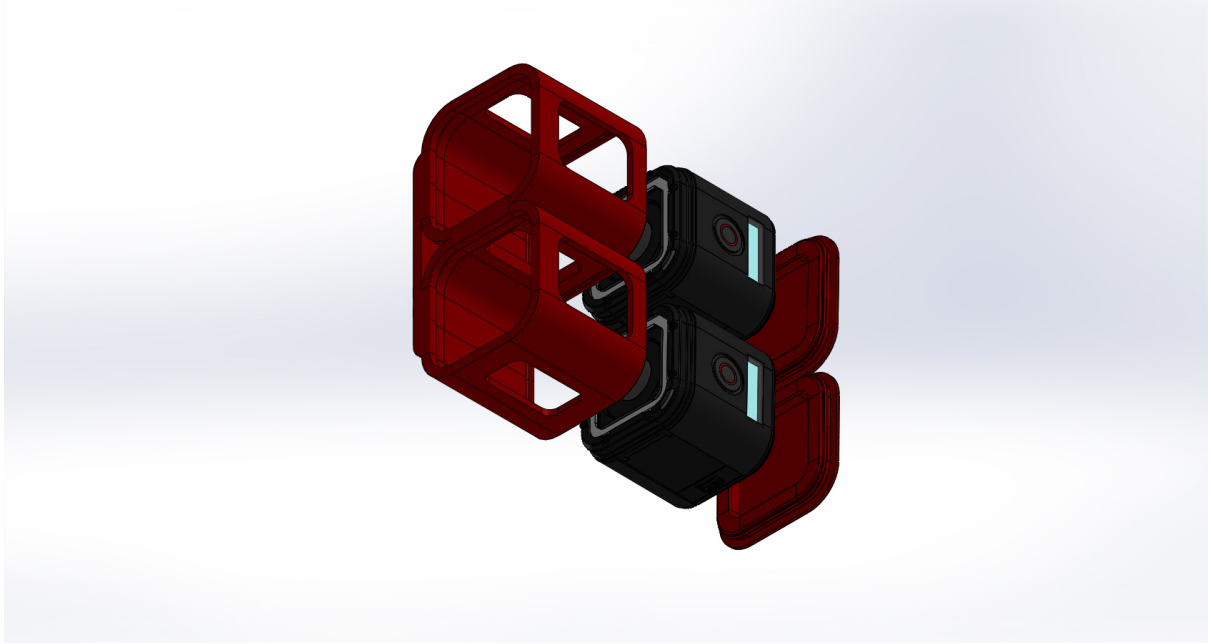


Figure 4.3: angle 1

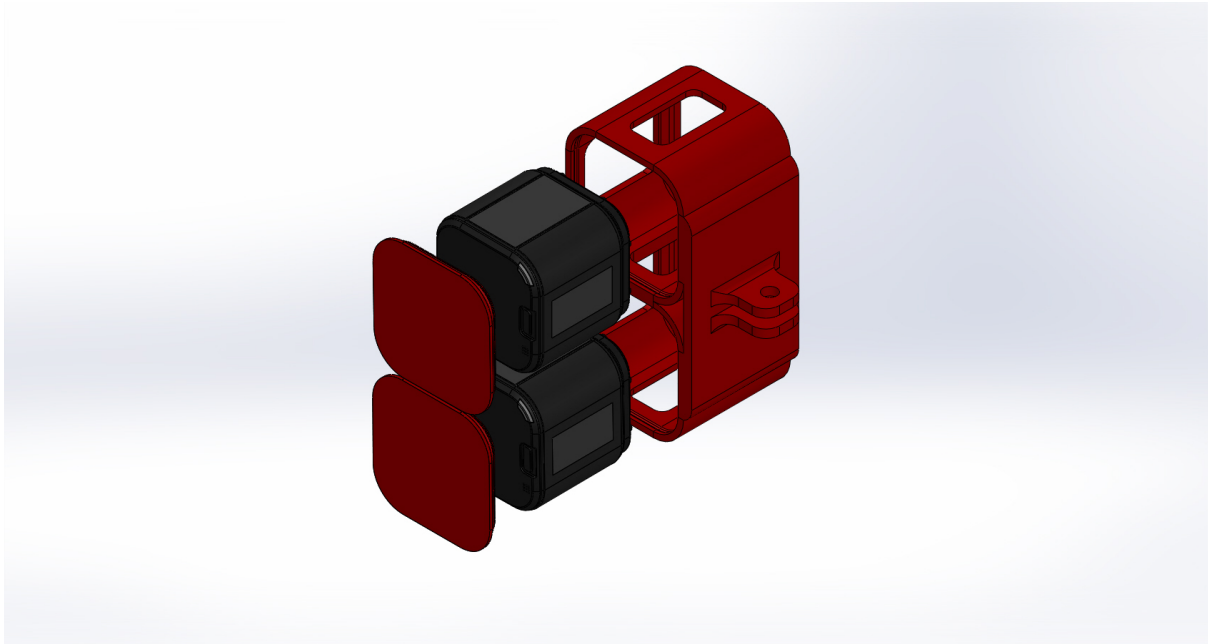


Figure 4.4: angle 2

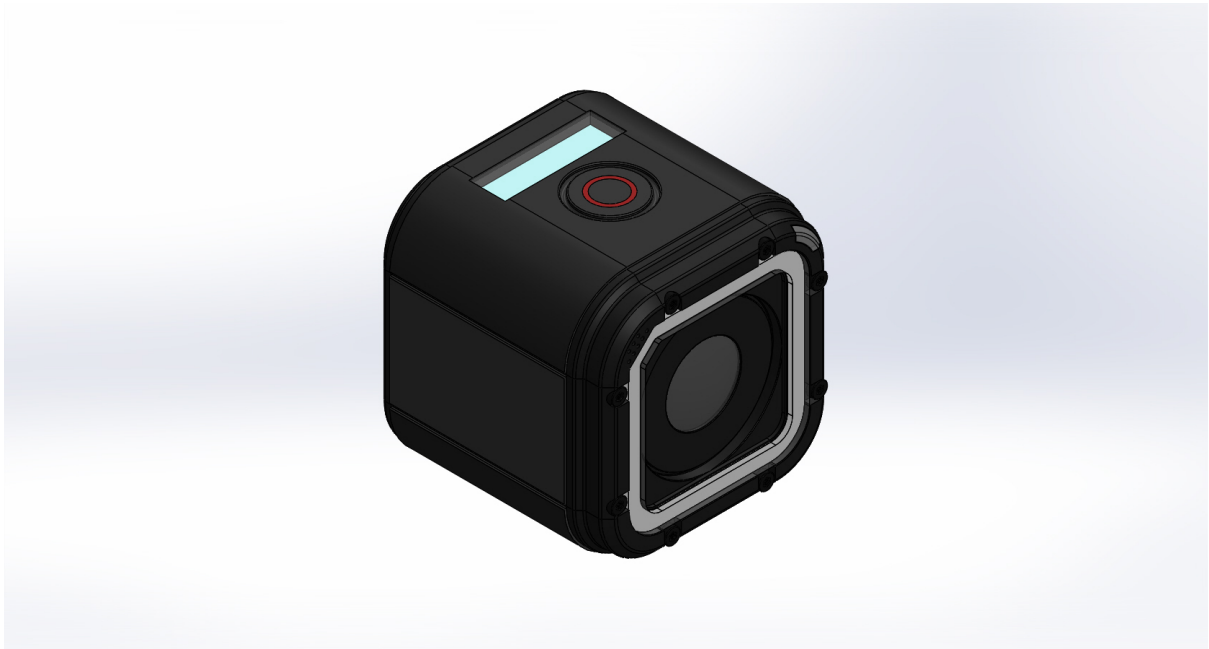


Figure 4.5: Solidworks model of the GPHS Action Camera from [18]

## Chapter 5

# Processing the Captured Data

# Chapter 6

## Data Fusion and State Estimation

State	Description
$x_{body}$	x Position of body w.r.t. the global frame
$y_{body}$	y Position of body w.r.t. the global frame
$z_{body}$	z Position of body w.r.t. the global frame
$\theta_{body}$	Pitch of body w.r.t. the global frame
$\phi_{body}$	Roll of body w.r.t. the global frame
$\psi_{body}$	Yaw of body w.r.t. the global frame
$\theta_{LH}$	Pitch of left thigh w.r.t. left hip
$\psi_{LH}$	Yaw of left thigh w.r.t. left hip
$\theta_{LK}$	Pitch of left calf w.r.t. left knee
$\theta_{LA}$	Pitch of left foot w.r.t. left ankle
$\theta_{RH}$	Pitch of right thigh w.r.t. right hip
$\psi_{RH}$	Yaw of right thigh w.r.t. right hip
$\theta_{RK}$	Pitch of the right calf w.r.t. right knee
$\theta_{RA}$	Pitch of the right foot w.r.t. the right ankle

Table 6.1: My caption

## Chapter 7

### Results, verification and Discussion



## Chapter 8

### Conclusions and Future Work

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