Chapter 1

Processing the Captured Data

This chapter is dedicated to the complex process of extracting critical data from the video files and IMU csv.

1.1 Processing the IMU Data

The following flowcharts depicts the procedural processing of IMU data.

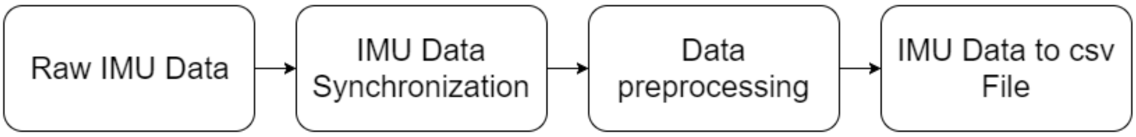

Figure 1.1: Diagram showing the progression and dependence of the major stages of video processing in the project

1.1.1 Obtaining IMU Data

To use the smartphone as an IMU a free application "AndroSensor" [1] was installed. This application could log parameter from all the sensor s and could be configured in various ways

The IMU data logged by the smartphone was saved as a .CSV file with the first row containing the headings of various variables. These headings were

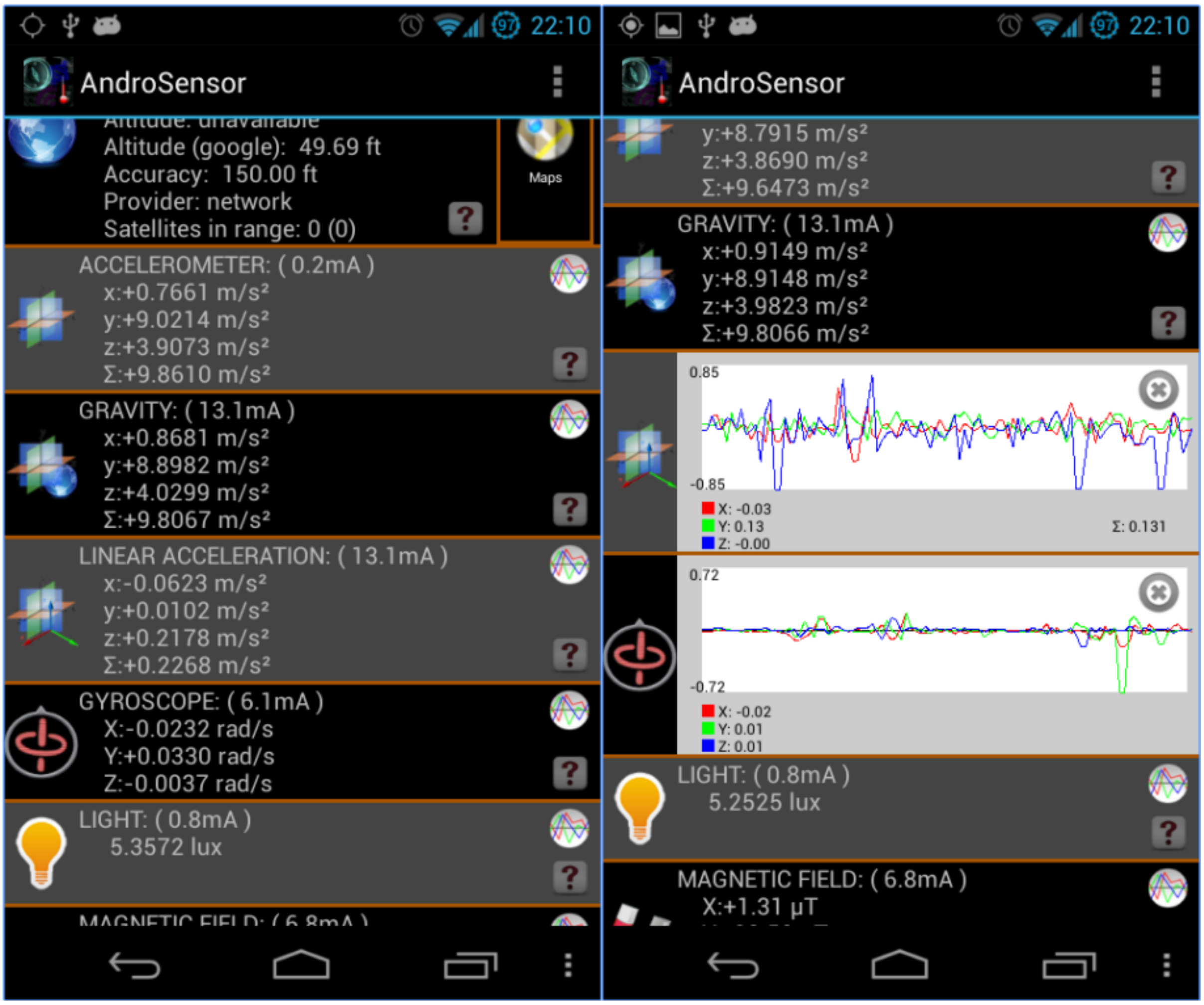

Figure 1.2: Androsensor Screenshots from [1]

All these variables have been recorded with respect the smartphone frame of reference as shown below

1.1.2 Synchronizing IMU Data

1.1.3 Preprocessing IMU Data

Before we can apply the IMU data directly to the EKF we need to make some minor modifications to the data. This is critical in removing any bias from the sensors. MEMS inherently have some

Heading	Fields
ACCELEROMETER	X,Y,Z
GRAVITY	X,Y,Z
LINEAR ACCELERATION	X,Y,Z
GYROSCOPE	X,Y,Z
MAGNETIC FIELD	X,Y,Z
ORIENTATION	X,Y,Z
ATMOSPHERIC PRESSURE	
LOCATION Latitude	
LOCATION Longitude	
LOCATION Speed	
LOCATION ORIENTATION	

Table 1.1: This table shows the different headings of the output IMU file

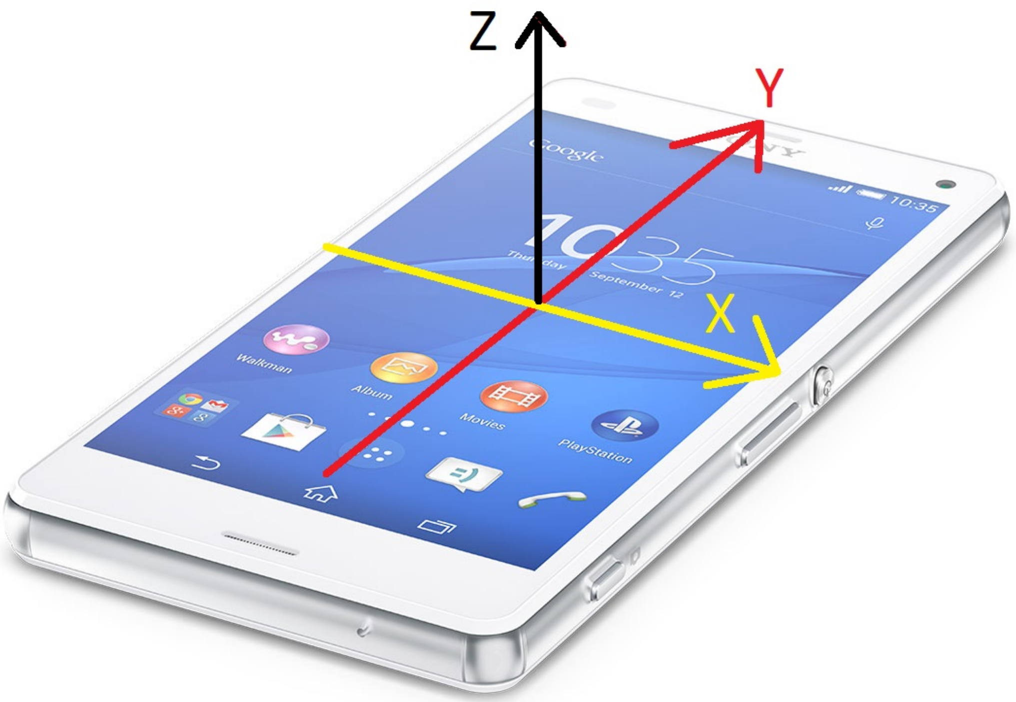

Figure 1.3: Figure demonstrating the frame of reference of the smartphone

1.1.4 Exporting IMU Data

1.2 Processing the Video Data

The following digram shows the process of converting a data heavy video file to a more lightweight .csv (Comma Separated Values) file.

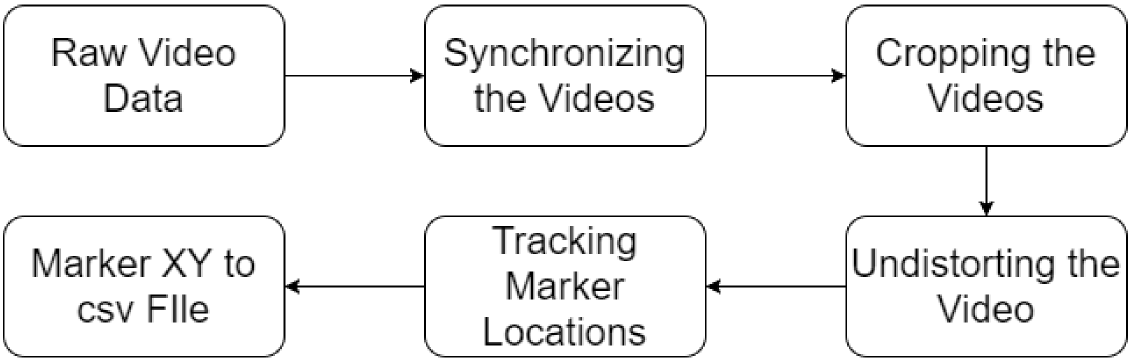

Figure 1.4: Diagram showing the progression and dependence of the major stages of video processing in the project

1.2.1 Obtaining Video Data

Using the chest mounted cameras detailed in the previous chapter we can generate raw video data. The GPHS cameras can be configured to record at different frame rates and resolutions as discussed in the previous chapter. The video files where stored in an .MP4 format. This meant that during recording the video was compressed and the

1.2.2 Synchronizing Video Sources

I typical problem faced when working with different sources of data is that of synchronization. Since this project used 4 different cameras, synchronizing the video sources are critical to generate accurate stereo vision data.

The problem of synchronization was overcome by using a audio cue to align the video data post capturing. With all systems recording, a simple hand clap can serve as a spiking audio input easily identified in the audio track of the video streams. The frame associated with this audio spike can be identified using SVP (Sony Vegas Pro) video editing software as shown in the figure below.

The red track in the above figure shows the recorded audio stream while the corresponding frames are displayed in the blue track above that. The cursor is aligned with the audio spike caused by the clap with the corresponding frame number displayed below the playback controls.

This method was repeated for every video stream such that a common starting point was generated.

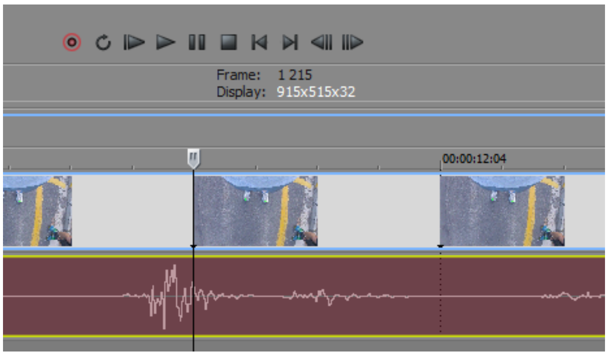

Figure 1.5: Figure showing the user interface of SVP video editing software

1.2.3 Cutting Critical Video Data

With the video data synchronized the next step was to generate a subset of video demonstrating a transient period and steady state period of running. From accelerometer readings we can easily determine the gait cycle period of our subject; that is the amount of time take between the same foot impacting the ground. These impacts are visible as spikes as seen in the accelerometer data.

1.2.4 Undistorting the Video Data

To generate accurate distances using stereo vision the video frames need to be undistorted.

Distortion of the frames is a result of the

To gain further understanding of undistorting video files [2] served as a reference. In this work Hartley describes various methods of undistorted images. These distortions are due to various lens effects.

1.2.5 Tracking and Exporting Marker Positions in the Frame

This section discusses the different methods of feature detection subdividing them into two main methodologies: automated and semi-automated. Each of these approaches offer advantages and disadvantages.

The final approach considered and used was to manually label critical point in the image using a toolbox created by Hedricket al. [3]. This software allows for a semi automatic tracking of points of interest in the video frames.

Chapter 2

Data Fusion and State Estimation

This chapter is dedicated the explaining the mathematical methods and models used to fuse data generated by the cameras and IMU.

State	Description
x_{body}	x Position of body w.r.t. the inertial frame
y_{body}	y Position of body w.r.t. the inertial frame
z_{body}	z Position of body w.r.t. the inertial frame
θ_{body}	Pitch of body w.r.t. the inertial frame
ϕ_{body}	Roll of body w.r.t. the inertial frame
ψ_{body}	Yaw of body w.r.t. the inertial frame
θ_{LH}	Pitch of left thigh w.r.t. left hip
ψ_{LH}	Yaw of left thigh w.r.t. left hip
θ_{LK}	Pitch of left calf w.r.t. left knee
θ_{LA}	Pitch of left foot w.r.t. left ankle
θ_{RH}	Pitch of right thigh w.r.t. right hip
ψ_{RH}	Yaw of right thigh w.r.t. right hip
θ_{RK}	Pitch of the right calf w.r.t. right knee
θ_{RA}	Pitch of the right foot w.r.t. the right ankle

Table 2.1: Table showing the different states of the model to be determined by the kalman filter.

we will use derivatives

al the derivatives

$$q = [x_{body}\ y_{body}\ z_{body}\ \theta_{body}\ \phi_{body}\ \psi_{body}\ \theta_{LH}\ \psi_{LH}\ \theta_{LK}\ \theta_{LA}\ \theta_{RH}\ \psi_{RH}\ \theta_{RK}\ \theta_{RA}]$$

all the states totalling 42 states

$$Q = [q\ \dot{q}\ \ddot{q}]$$

all 42 and their equations

positional

$$\ddot{x}_{k+1} = \ddot{x}_k + \sigma^2_{\ddot{x}}$$

$$\dot{x}_{k+1} = \dot{x}_k + \ddot{x}_k T + \sigma^2_{\dot{x}}$$

$$x_{k+1} = x_k + \dot{x}_k T + \sigma^2_{x}$$

angular

$$\ddot{\theta}_{k+1} = \ddot{\theta}_k + \sigma^2_{\ddot{\theta}}$$

$$\dot{\theta}_{k+1} = \dot{\theta}_k + \ddot{\theta}_k T + \sigma^2_{\dot{\theta}}$$

$$\theta_{k+1} = \theta_k + \dot{\theta}_k T + \sigma^2_{\theta}$$

since all states are either positional(body) or angular(body and limbs) matrices: rotational matrices

$$\text{x axis} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & -\sin\phi \\ 0 & \sin\phi & \cos\phi \end{bmatrix}$$

$$\text{y axis} \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix}$$

$$\text{z axis} \begin{bmatrix} \cos\psi & -\sin\psi & 0 \\ \sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

solving for the angles

front cameras

point 1 right knee

point 2 left knee

point 3 right foot

point 4 left foot

back cameras
point 1 right calf
point 2 left calf
point 3 right heel
point 4 left heel

front
right knee

$$p1xyz = bodyY + bodyZ + R1 * Thigh$$

left knee

$$p2xyz = bodyY + bodyZ + R1 * Thigh$$

right foot

$$p3xyz = bodyY + bodyZ + R1 * Thigh + R2 * Calf + R3 * Foot$$

left foot

$$p4xyz = bodyY + bodyZ + R1 * Thigh + R2 * Calf + R3 * Foot$$

back
right calf

$$p1xyz = bodyY + bodyZ + R1 * Thigh + R2 * 0.5 * Calf$$

left calf

$$p2xyz = bodyY + bodyZ + R1 * Thigh + R2 * 0.5 * Calf$$

right heel

$$p2xyz = bodyY + bodyZ + R1 * Thigh + R2 * Calf$$

left heel

$$p2xyz = bodyY + bodyZ + R1 * Thigh + R2 * Calf$$

2.1 Understanding the Data Sources

It is important to understand the different parameters that mathematically quantify cameras. These parameters can be devided into *extrinsic* and *extrinsic*. Extrinsic camera variables related to the cameras position in the inertial frame and the direction the camera is facing. These can be summarized by the extrinsic camera matrix

$$[R \,|\, \boldsymbol{t}] = \left[\begin{array}{ccc|c} r_{1,1} & r_{1,2} & r_{1,3} & t_1 \\ r_{2,1} & r_{2,2} & r_{2,3} & t_2 \\ r_{3,1} & r_{3,2} & r_{3,3} & t_3 \end{array}\right]$$

2.2 State Estimation

This section will mathematically explain the Kalman filter and its implementation in this project.

Process equation of the kalam filter. from states to emasurements

$$X_{k+1} = FX_k + w_k$$

our state, contained in the vector X can be estimated by applying the process matrix F to our current known state. the term w is the noise variable that accounts for process noise.

Measurement equations from measurements to states.

$$Y_k = H_k X_k + v_k$$

w will be contained int he matrix Q

while v will be contained in the matrix R1

linearizing nonlinear system we get the EKF

2.3 Q Matrix, R Matrix and Initialization

This section will discuss the final components of the EKF namely the Q matrix containing the various process noise variations, R matrix containing the various measurement noise variances and the initial state values.

Chapter 3

Results, Verification and Discussion

This chapter is dedicated to discussing the results generated and their verification.

3.1 Results

3.2 Verification

3.3 Discussion

Chapter 4

Conclusions and Future Work

This chapter is dedicated to drawing conclusions based on results found and make recommendation on future iterations of this project. Since the underlying methodology is quite novel this system should serve as the foundational step to a fully automated motion capture system.

4.1 Conclusion

Due to the relatively small dataset used in this project it serves cannot serve as more than a proof of concept.

4.2 Future work

The system was originally designed with four cameras due to the availability of equipment and the assumption that stereo vision would be implemented. From this a set of front and rear mounted cameras would be necessary. Originally there was an intention to reduce the total amount of cameras.

The iterative design would have followed the following mapping. Initially using 4 cameras and an smartphone as a sensor. reducing the system to two cameras (one mounted to the back of the runner and one mounted to the chest of the runner) and a smartphone as a sensor. The next iteration would use the the smartphone camera at the front and a single camera at the back whilst using the smartphone as a sensor as well. This system greatly reduces the cost of the original design philosophy, even given that a powerful and modern smartphone would be used. The final iteration would use only the smartphone at the front as a single camera and sensor. For this method to work the estimation algorithm would need to better understand the periodic motion of the human gait and the model would need to increase in complexity.

Due to the labour intensive approach taken to image processing a further avenue for improvement is the automation of feature detection. The progression would start from the current implementation of markers and use a semi-automatic toolbox to identify critical points on the image. Next computer algorithms should be created to automate the image processing with markers. This could allow for much longer runs and larger datasets to be studied, introducing elements such as fatigue and other running modifiers. THe next iterative step would be to remove the markers from the runner such that the setup time of the system is reduces. This is a difficult problem to solve using classical image processing as the variables relating to the runner and the environment are not constant. Perhaps a neural network can be trained to identify the different elements of the lower limbs.

These improvements would decrease the overall cost of the system and optimize the the process substantially. This decrease in hardware does imply that the complexity of the underlying algorithms and models would increase. This trade-off can be considered for future work.

Application for Approval of Ethics in Research (EiR) Projects
Faculty of Engineering and the Built Environment, University of Cape Town

APPLICATION FORM

Please Note:
Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data.The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook**(available from the UCT EBE, Research Ethics website) prior to completing this application form: http://www.ebe.uct.ac.za/usr/ebe/research/ethics.pdf

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		Johann Hendrik Joosten
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Preferred email address of applicant:		joostenhendrik@gmail.com
If a Student	Your Degree: e.g., MSc, PhD, etc.,	B.Sc(Eng) Mechatronics
	Name of Supervisor (if supervised):	Dr. Amir Patel
If this is a researchcontract, indicate the source of funding/sponsorship		-
Project Title		Modelling the Kinematics of the Human Lower-Limbs using Cameras and an IMU

I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

SIGNED BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Johann Hendrik Joosten	JH Joosten	22/08

APPLICATION APPROVED BY	Full name	Signature	Date
Supervisor (where applicable)	AMIR PATEL		22/08/2017
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section1; and for all Undergraduateresearch (Including Honours).	S. CHOWDHURY	Sunil Chowdhury	11/10/17

Figure 4.1: ethics clearance

Bibliography

[1] F. Asim, "Androsensor," https://play.google.com/store/apps/details?id=com.fivasim.androsensor&hl=en, [Online; accessed 10-October-2017].

[2] R. I. Hartley and A. Zisserman, *Multiple View Geometry in Computer Vision*, 2nd ed. Cambridge University Press, ISBN: 0521540518, 2004.

[3] T. L. Hedrick, "Software techniques for two-and three-dimensional kinematic measurements of biological and biomimetic systems," *Bioinspiration & biomimetics*, vol. 3, no. 3, p. 034001, 2008.