TRAJECTORY ANALYSIS OF BALL BASED ON IMAGE PROCESSING AND SIMULATION

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TRAJECTORY ANALYSIS OF BALL BASED ON IMAGE PROCESSING AND SIMULATION

By

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LIST OF SYMBOLS

A	Cross-sectional Area of Projectile
C_D	Dimensionless Drag Coefficient
C_L	Dimensionless Lift Coefficient
d	Projectile Diameter
$\overrightarrow{F_D}$	Drag Force, Magnitude
$\overrightarrow{F_G}$	Gravitational Force, Magnitude
$\overrightarrow{F_L}$	Lift of Magnus Force, Magnitude
$\overrightarrow{F_u}$	Buoyant Force, Magnitude
g	Acceleration due to Gravity
m	Projectile Mass
Vx	Velocity in the x direction
Vy	Velocity in the y direction
Vz	Velocity in the z direction
$\overrightarrow{\omega}$	Projectile Angular Velocity
Θ	Angle between and $\vec{V}$ and$\overrightarrow{\omega}$.
ρ	Density of air

ANALISIS TRAJEKTORI BOLA BERDASARKAN PEMPROSESAN IMEJ DAN SIMULASI

ABSTRAK

Disertasi ini adalah berkaitan analisis trajektori bola berdasarkan pemprosesan imej dan simulasi. Data yang digunakan dalam disertasi adalah dua video untuk menentukan parameter permulaan yang boleh menjejaskan trajektori bola tenis meja dan bola sepak. Objektif disertasi ini adalah untuk memplotkan dan menganalisa trajektori bola. Teknik pemprosesan imej digunakan untuk menangkap unjuran. Motivasi penyelidikan ini adalah untuk menentukan kewujudan putaran dalam trajektori dengan parameter awal tidak diketahui. Video pertama adalah video berkelajuan tinggi yang dirakam pada 1000 bingkai sesaat. Video berkelajuan tinggi merakam unjuran awal bola tenis meja. Putaran tidak diketahui, oleh itu melalui simulasi Matlab kewujudan putaran ditentukan. Parameter awal dari video dikira bagi tujuan replikasi unjuran secara matematik. Video kedua adalah video penyiaran langsung yang dirakam pada kira-kira 30 bingkai sesaat. Video ini dianalisis dalam pandangan tiga dimensi untuk menentukan kewujudan putaran. Jenis putaran sama ada bola sepak mengalami putaran atas, putaran belakang atau putaran tepi juga dianalisis. Penemuan disertasi ini membuktikan kewujudan putaran atas apabila bola tenis meja dilancarkan. Bola sepak dalam video ini mempunyai putaran belakang ketika bergerak ke arah y-z. Trajektori bola sepak dan bola tenis meja berjaya diplotkan.

TRAJECTORY ANALYSIS OF BALL BASED ON IMAGE PROCESSING AND SIMULATION

ABSTRACT

This dissertation is about trajectory analysis of ball based on image processing and simulation. Data used in this dissertation are two videos to determine the initial parameters that can affect the trajectory of the table tennis ball and football. Objective of this dissertation is to plot and analyse the trajectory of balls. Image processing techniques were used to capture the projection. The motivation of this research is to determine the existence of spin in a trajectory where the initial parameters are unknown. The first video was a high speed video captured at 1000 frame per second. The high speed video captured the initial projection of a table tennis ball. The spin is unknown; therefore through Matlab simulations the existence of spin is determined. Initial parameters from the video are computed in order to replicate the projectile mathematically. The second video is a broadcasting video that captured at approximately 30 frames per second. This video was analysed in a three dimensional view to determine the existence of spin. The type of spin whether the football was experiencing topspin, backspin or sidespin was also analysed. The findings of this dissertation shows the existence of topspin when the table tennis ball was launched. The football in the video had a backspin while moving in the y-z direction. The projectile of the football and table tennis ball is successfully plotted.

CHAPTER 1

INTRODUCTION

1.1 Background

One of the major physics theory involved in table tennis is projectile motion. Projectile motion has been studied for many centuries in physic community. Galileo was the first to accurately describe projectile motion [1]. He proved that it could be understood by analysing horizontal and vertical components separately.

Various analytical methods have been developed in the past to study the projectile motion of balls. However, all proposed approximate analytical solutions are rather complicated and inconvenient for educational purposes. This is why projectile motion needed to be described in simple approximate analytical formula. In Chudinov's article, comparatively simple approximate analytical formulas have been obtained to study the motion of the projectile in a medium with a quadratic drag force [3]. Formulas are used to solve the classical problem of maximizing the projectile distance. Analytical approximations of the projectile trajectories were investigated. The calculation of the projectile distance was computed in wide ranges of variation of the initial velocity and launch angle. This article aims to extend the application field of the formulas and to compare the accuracy of these formulas for calculating the projectile range with the results.

In R. D. H. Warburton's & J. Wang's paper, the problem of the motion of a projectile thrown at an angle to the horizon is studied [4]. The trajectory of the projectile is a parabola. Analytical formulas have been derived for basic functional dependences of the problem, including the trajectory equation in Cartesian coordinate s. Also this description includes the determination of the optimum throwing or initial angle and maximum range of the motion.

Based on the research the relative error is about 1 to 2 % for the derived analytical formulas. The proposed formulas make it possible to carry out an analytical investigation of the motion of a projectile.

Projectile motion is the study of how objects fly through air at different initial angles and the maximum distance achieved by the projectile. Three important variables include gravity, horizontal force and air resistance. The interaction of a spinning ball with the atmosphere is known as the Magnus force. During a projectile the ball experiences drag force and, if the projectile is spinning, a second force that gives lift to the ball; which is called the Magnus force is produced.

Image processing is the future of multimedia information processing. Image processing has many and diverse applications. There are two major areas of application of digital image processing techniques which are the improvement of pictorial information for human interpretation and processing of scene data for autonomous machine perception. In machine perception, interest focuses on procedures for extracting from image information in a form suitable for computer processing.

The challenges to track the ball in a broadcast video is ball size is too small in different angles and views. Based on various lighting conditions, the ball may not be visible. Tracking the ball based on trajectory is complicated as the ball moves fast. In this context of tracking a tennis ball, noise is a big issue because of the ball size. Due to the quality of the frame, noise appears very frequently among images, which interferes with the process of object detection. Traditional background subtraction approach is not capable of eliminating the majority noise and they usually require additional operations. A modified background subtraction approach is applied to overcome the limitations due to bad quality of the captured images. Based on the research paper titled, Object Detection and Tracking based on

Trajectory in Broadcast Tennis Video, a model was developed to improve ball and player tracking in broadcast videos. It does not only increase the accuracy in identifying the ball, but also improves the accuracy in determining the ball projection position. Frame difference technique is used to consider difference between current frame and next frame. The logical AND operation is done in the created background image to obtain image difference result. The ball and player are detected [5].

For table tennis or a football game, the projectile motion of the table tennis ball can be examined by applying image processing techniques onto the sport video. The information extracted from the projectile motion such as initial velocity in different axes, initial angles, and duration of the projectile can be used for further analysis. The existence of spin in various axes can be determined by comparison with original image processing data.

The first video used in this dissertation captured the projectile of a table tennis ball. The second video that is used in this dissertation is the free kick by Faiz Subri, who is the runaway winner of the 2016 FIFA Puskas Award for his physics-defying goal in a league match in 2016. The Puskas award was established in 2009 with the likes of Cristiano Ronaldo, Zlatan Ibrahimovic and Neymar among its previous winners [2].

There has been extensive study on the physics of sports and the aerodynamic properties of various objects. The standard references include the study on smooth and rough spheres. The understanding of the physics of soccer balls has widened in the past decade. The influence of drag force and Magnus force are discussed. The simulation of the trajectory of a ball moving in air can be done by solving the relevant differential equations. Reynolds's number is an important number used to describe phenomena associated with balls moving through air [6].

1.2 Problem Statements

The initial parameters such as angular velocity, initial elevation angle and initial velocity of the ball which is launched by the launcher is not known for the videos that were analysed. Image processing techniques is useful to determine the projectile motion of balls moving in air through analysing the images of the moving ball. The simulation results from mathematical analysis can be compared to the results that obtained using image processing techniques.

In general, to determine whether a ball spins during a projectile motion is not clearly visible to the spectators. The existence of spin in the trajectory of balls that are recorded cannot be judged by visual observations. There is a need to derive equation and plot the projectile mathematically in order to determine the existence of spin.

Not only that, the next problem is parameters that are unknown such as the angular velocity. There is a need to determine the angular velocity to deduce the type of spin. During the famous free kick by Faiz Subri, it is uncertain of the type of spin the football experiences, whether it is a topspin, backspin or sidespin. By using initial parameters to simulate a mathematical analysis, and through comparison of simulations, the existence of spin can be determined.

1.3 Objectives

Objectives of this dissertation include:

1 To determine the initial parameters that can affect the trajectory of the table tennis ball and football

2 To capture the projectile of different balls using image processing techniques

3 To analyse the possibility of spin during a projectile.

1.4 Scope of the Research

The first part of this project focuses on the simulation of projectile motion of a table tennis ball. Forces acting on the ball moving in the air are determined. The equations of the relevant forces are identified. The numerical solution is solved using Matlab. The initial parameters of the table tennis ball are obtained from the video recordings. The high speed video recordings is analysed in two dimensions.

The second part of this project will focus on the image processing techniques of the free kick by Faiz Subri. The video is processed to determine initial velocities. With the aid of the initial parameters, the existence of spin and type of spin is determined. Other fixed conditions in this part of the project are the distance of Faiz Subri from the goal post and goal line. The live recording is analysed in three dimensions.

1.5 Dissertation Outline

This thesis consists of five chapters. In chapter 1, background of table tennis ball, football and projectile motion are discussed. The objectives and scope of research are clearly outlined in this chapter. Chapter 2 covers the literature review of this thesis. This chapter discusses how drag and lift acting on a ball is affected. It also illustrates spin magnitudes that can be induced on a ball. Past works related to this project are presented in this chapter. The theories of the forces acting on projectile are discussed in this chapter.

Methodology of this project is discussed in Chapter 3. This chapter covers overall project implementation flow, description of steps in the project flow, dissertation procedure, image processing, data analysis, Matlab software, ODE45 Tool and trajectory simulation. Chapter 4 comprises the simulation results of the projectile motion and the results obtained using image processing techniques. Analysis and discussion are also presented based on the results. Trajectory of both the table tennis ball and football are analysed in this chapter. Finally, the conclusion of the project is presented in chapter 5. This chapter ends with the suggestion for future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Trajectory of ball is affected by various factors such as the existence of air. The forces come with the existence of air has to be considered in investigating the projectile motion of a moving table tennis ball or a football in air. This chapter presents the theories that involved in the trajectory of projectile. The relationship between Reynolds's number, laminar and turbulent air flow and drag coefficient is discussed. Magnus force in a projectile is analysed. Simulink model of a projectile motion is also discussed in this chapter.

2.2 Forces Acting on Trajectory

Projectiles can be analysed using different number of axis. The very basic projectile can be analysed by only considering gravitational force.

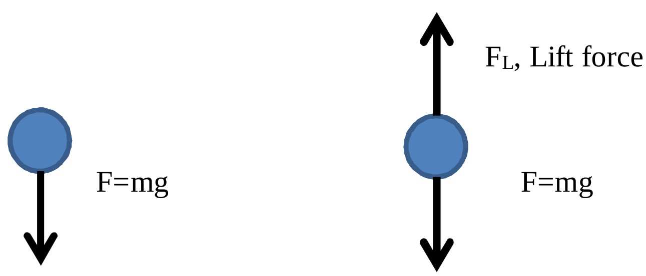

Figure 2.1: Forces acting on a ball.

The ball on the left shown in Figure 2.1 is the gravitational force acting on a ball when the air resistance is neglected. Gravitational force, F is the product of mass, m and gravitational constant, g. The ball on the right is when lift force is present. Lift force is present when the ball experiences spin.

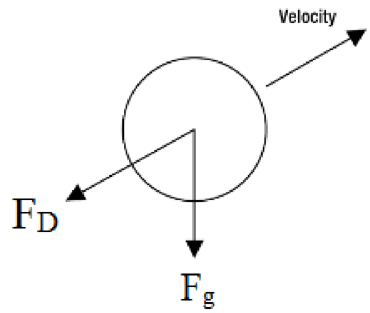

Figure 2.2: The force diagram with gravity and drag effects [8].

The force balance diagram when drag is added to the gravity is shown in Figure 2.2. There are two forces acting on the projectile, gravity, F_g that acts in the vertical direction and drag, F_D that acts in a direction opposite to the velocity vector.

A flying tennis ball is affected by three types of forces which are gravity, drag and lift. Lift force is the result of spinning of the ball. This is called the Magnus effect. Drag force is the component of the aerodynamic force appearing during the motion of the solid. It acts opposite to the direction of motion [7]. The magnitude of the drag force is usually written as Equation 2.1 [8].

$$F_D = \left|\overrightarrow{F_D}\right| = \frac{1}{2}\rho\, A\, C_D V^2 \tag{2.1}$$

Where ρ is the air density, A is the cross-sectional area of the spherical projectile, C_D is the (dimensionless) drag coefficient and V is the projectile's velocity relative to the air [9].

In vector form:

$$\overrightarrow{F_D} = \frac{1}{2}\rho A C_D V^2.\left(-\hat{V}\right) \tag{2.2}$$

Where $\hat{V}$ is a unit vector in the direction of $\vec{V}$. The drag coefficient C_D is in fact dependent on V based on Equation 2.2 [8]. The flow pattern around objects moving through a fluid is usually characterized by a dimensionless number proportional to the velocity known as the Reynolds number, R_e [6]. For smooth surfaces, the drag coefficient C_D remains constant at 0.45. Since table tennis ball and football have smooth surfaces unlike golf balls, C_D will be assumed to be constant at 0.45 and hence F_D will be proportional to V^2.

2.3 Magnus Force

If a player imparts spin to the soccer ball, as might happen for a free kick or a corner kick, the ball may curve more than it would if it were not spinning. Forces associated with the spinning ball are usually parameterized by the Reynolds number and by the dimensionless spin parameter, *Sp*, which is the ratio of the rotating ball's tangential speed at the equator to its centre-of-mass speed with respect to the air. For a ball of radius *r*, angular speed *ω*, and center-of-mass speed *v*, dimensionless spin parameter *Sp* is given in Equation 2.3 [8].

$$S_p = \frac{r\omega}{v} \tag{2.3}$$

Next, another force that acts on a flying ball is the lift force with spin about an arbitrary axis. For spins perpendicular to the projectile velocity the lift or Magnus force is proportional to V^2 and to act at right angles to both $\vec{V}$ and $\vec{\omega}$ [10]. The Magnus force is defined in Equation 2.4 [8].

$$F_L = \left|\vec{F_L}\right| = \frac{1}{2}\rho A C_L V^2 \tag{2.4}$$

where C_L is the (dimensionless) lift coefficient, ρ is the air density, A is the cross-sectional area of the spherical projectile, and V is the projectile's velocity relative to the air.

The Magnus effect is perpendicular to the velocity. Rotating ball influences the surrounding air and makes it rotate too. F_L Is assumed to vary smoothly as sin θ where θ is the angle between $\vec{V}$ and $\vec{\omega}$ and varies from 0° to 180° [11]. The lift force may be written in vector form based on Equation 2.5 and Equation 2.6 [8].

$$F_L = \frac{1}{2}\rho A C_L V^2 sin\theta . \hat{n} \tag{2.5}$$

Where $\hat{n}$ is a unit vector in the direction of $\overrightarrow{V \times} \vec{\omega}$ and

$$\hat{n} = \frac{\vec{V} \times \vec{\omega}}{|\vec{V} \times \overrightarrow{\omega|}} \tag{2.6}$$

The lift coefficient C_L is in a general function of angular velocity, *w* based on Eqution 2.7 [8].

$$C_L = 3.19 \times 10^{-1}[1 - \exp((-2.48 \times 10^{-3})\ w)] \tag{2.7}$$

Equations 2.1, 2.4 and 2.7 are used in the ODE45 solver to compute the projectile mathematically. Refer to Appendix A.

Garry Robinson and Ian Robinson emphasize in their work that the equations and coefficients regarding the drag force and lift force consists of considerable uncertainty in their actual formulas and values [11]. This project follows the work of that paper to generate trajectory of a moving table tennis ball so that the simulation results can be compared to the results obtained using image processing techniques.

A spin ensures the football can pass over certain significant distance. A spin is also responsible to form a curve in the projectile motion. As seen in previous figures, when angular velocity is assumed to be zero, the projectile is close to a linear motion. A spin creates a lift because there is the flow of air. There are air molecules that lie close to the surface of the ball. These air molecules will affect the surrounding flow of air. When a ball spins, the air flow is also pulled in the direction of the spin. This pull in the air flow will generate force. The magnitude of force can be closely described as the integral of the pressure acting on the surface multiplied by the area around the ball.

A spinning or revolving object has angular velocity ω. The angular velocity is dependent on the force applied tangential to its surface. A larger torque produces a larger angular acceleration. A larger torque can be obtained by applying a larger force. The spin rate was determined by following a given point on the ball as the ball turned either a half turn for slow spins or a full turn for fast spins. Balls with smooth surfaces can manage to achieve a maximum spin rate of 125 rad/s to 180 rad/s [12].

Lift force acts perpendicular to air flow direction and the axis the ball is spinning around. Due to the induce air flow, it creates regions with different pressure creates an imbalance in the forces shown in Figure 2.3. Bernoulli’s principle states that the air travels faster relative to the centre of the ball. This reduces the pressure, according to Bernoulli's principle. The pressure increases on the other side of the ball, where the air travels slower relative to the centre of the ball. The imbalance in the forces causes the ball to deflect in the same sense as the spin. This lateral deflection of a ball in flight is generally known as the "Magnus effect" [13].

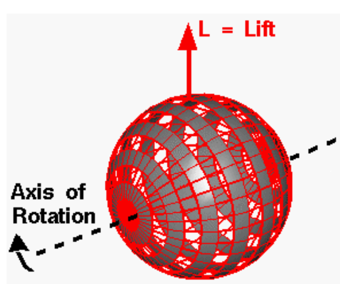

Figure 2.3: Lift force with respect to the axis of rotation [8].

An object moving through air can have F_R which represents the resultant force acting upon the object as shown in Figure 2.4. This result force F_R can be resolved into two components, Drag force,F_D directed opposite to the motion of the object and Lift force, F_L at right angles to the direction.

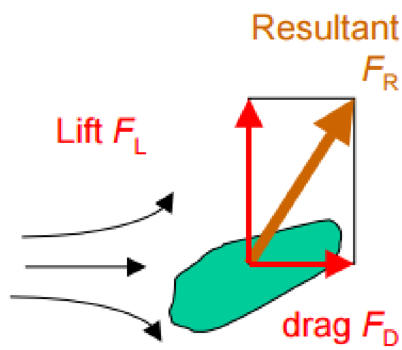

Figure 2.4: Resultant force acting on a moving ball [13].

2.4 Turbulent Airflow versus Drag Coefficient, C_D

Projectile flying through air experiences a drag as the resistance the surrounding air exerts on an object travelling through it. There are two general ways an object can travel through air. The surrounding air can travel smoothly and steadily over the object and is known as the laminar flow. Low Reynolds's number is associated with laminar air flow. As the Reynolds's number is increased, there is a point where the smooth laminar flow over the object transitions to a turbulent flow. Under turbulent flow conditions, the pressure difference is less than laminar flow conditions, and the drag component is lower.

If the football is kicked at high speed, it can change from laminar to turbulent airflow. By shifting to turbulent airflow, drag coefficient can be reduced significantly, compared to when it is in laminar airflow. Since football has a smooth surface, it has to be kicked relatively fast in order for it to change to turbulence [14]. When the air flow changes from laminar to turbulent, the drag coefficient changes from high to low. When the airflow is laminar and the drag coefficient is high as the boundary layer of air on the surface of the ball has a separation. When the airflow is turbulent, the boundary layer is closer to the ball for a longer period of time [15]. This produces late separation and a small drag.

2.5 Spin versus Lift Coefficient, C_L

In 1976 Peter Bearman and colleagues from Imperial College, London, carried out a classic series of experiments on golf balls. They found that increasing the spin on a ball produced a higher lift coefficient and hence a bigger Magnus force. However, increasing the velocity at a given spin reduced the lift coefficient. What this means for a football is that a slow-moving ball with a lot of spin will have a larger sideways force than a fast-moving ball with the same spin. So as a ball slows down at the end of its trajectory, the curve becomes more pronounced [9].

2.6 Knuckleball Theory

When the trajectory moves in a zigzag pattern, it is classifies as knuckleballs. These zigzag trajectories are associated to asymmetric and unsteady flows of air around the ball. When the lift forces experiences unsteadiness, there are possibilities of knuckleball occurrences. Unsteadiness of lift forces can produce a change in lateral directions within a field. This will in turn produce a sufficient magnitude to disturb players. Bases on the drag forces, in order to induce a large knuckleball effect, initial velocity should be taken into consideration. During a knuckleball phenomenon, initial spin is absent, thus opening possibilities for a knuckleball trajectory. The range of initial velocity is narrow therefore reduces the chances of knuckleball trajectories.

Due to the low chances of a knuckleball occurrence, this project focuses on pure topspin or pure backspin [16]. Knuckleball theory is however discussed here as it can be associated with small errors. When trying to detect the centre of the ball during the video analysis, the slightly erratic look to the data may come from knuckle-ball effects. This is associated when a ball is nonrotating.

2.7 Projectile Motion in Simulink

Simulink can also be used to analyse projectile motion. It is a system of equations or a single equation for a vector function. The position vector for the projectile is given by r = [x, y]. The projectile satisfies the second order equation $r'' = -g$ which is the gravitational acceleration. This can be solved using two integrators and setting up the system with a two component vector [17]. A drag force can be added to increase the complexity. Thus, to solve the system $r'' = -g - k v^2$, where k represents the mass of the object. The magnitude of the drag is proportional to v^2. If the projectile is moving second order differential, directly upward, the drag is negative, opposing the motion. The model will need functions to compute the speed, v, and will need two integrators with appropriate initial position and velocity. The gravitational force will also be provided with a constant block. This model is shown in Figure 2.5. The initial position is [0, 4] ft. and the initial velocity is [80, 80] feet./s. The gravitational constant is $-g = [0, -32]$ feet/s^2. The speed is always positive.

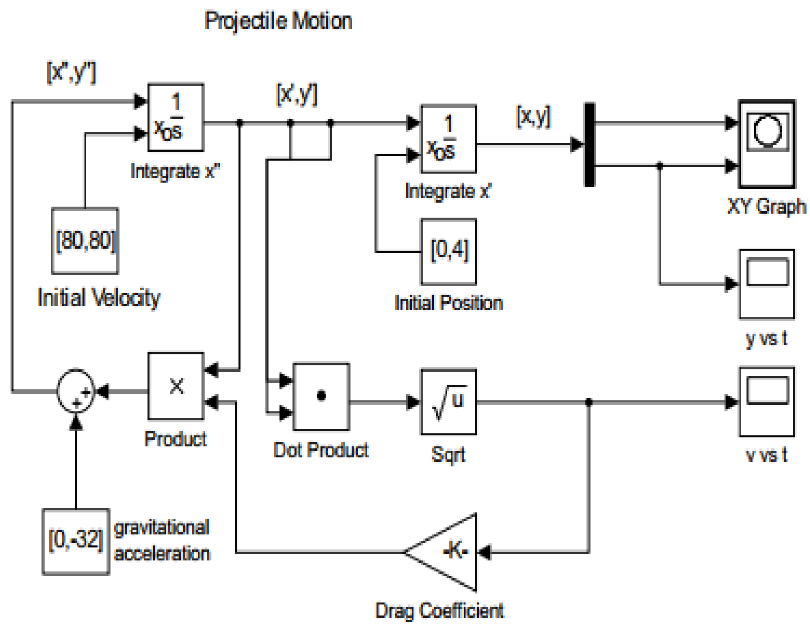

Figure 2.5: Projectile motion illustrated using Simulink [17].

2.8 Image Processing

Image processing is a method to perform various operations on an image, in order to enhance the image or to extract useful information from it. It is a type of signal processing in which input is an image and output may be image or characteristics/features associated with that image. Recently, image processing is among rapidly growing technologies as it is vastly used. There are three important steps in image processing which is to import the image via image acquisition tools; analysing and manipulating the image; obtain an output in which result can be altered image or report that is based on image analysis [21].

There are two methods used for image processing which is, analogue and digital image processing. Analogue image processing can be used for the hard copies like printouts and photographs. Digital image processing techniques help in manipulation of the digital images by using computers.

Image acquisition is the process of retrieving an image from a source. Performing image acquisition in image processing is always the first step in the workflow sequence because, without an image, no processing is possible. The image that is acquired is completely unprocessed and is the result of hardware that was used to generate it.

In order to perform image enhancement, the ‘bwlabel’ function can be used. This ‘bwlabel’ function converts the grayscale image to a binary image. The output image replaces all pixels in the input image with luminance greater than level with the value 1 (white) and replaces all other pixels with the value 0 (black). Level needs to be specified in the range of 0 to 1. This range is relative to the signal levels possible for the image's class. Therefore, a level value of 0.5 is midway between black and white, regardless of class. In this project a threshold value of 0.04 was used in order to capture ball with similar size in comparison with the original image. By deteriorating the diameter of the ball, may result inaccurate meter over pixel calculation.

Due to imperfections in the binary images, morphological image processing is conducted. This is because by using mere threshold values to convert an image to black and white, there may be noise and texture present Morphological image processing pursues the goals of removing these imperfections by accounting for the form and structure of the image. These techniques can be extended to grayscale images.

Morphological image processing conducts operations related to the shape or morphology features in an image. Morphological techniques probe an image with a small shape or template called a structuring element. The structuring element is positioned at all possible locations in the image and it is compared with the corresponding neighbourhood of pixels.

Some operations test whether the element "fits" within the neighbourhood, while others test whether it "hits" or intersects the neighbourhood.

The structuring element is a small binary image, each with a value of zero or one. The structuring element will try to fit the image if, for each of its pixels set to 1, the corresponding image pixel is also 1. Similarly, a structuring element is said to hit, or intersect, an image if, at least for one of its pixels set to 1 the corresponding image pixel is also 1 [21].

Morphological filtering of a binary image is conducted by considering compound operations like opening and closing as filters. They may act as filters of shape. For example, opening with a disc structuring element smoothen corners from the inside, and closing with a disc smoothen corners from the outside. But also these operations can filter out from an image any details that are smaller in size than the structuring element. Opening is filtering the binary image at a scale defined by the size of the structuring element. Only those portions of the image that fit the structuring element are passed by the filter; smaller structures are blocked and excluded from the output image. The size of the structuring element is most important to eliminate noisy details but not to damage objects of interest.

One of the most important aspects is to create a Matlab sequence that is able to detect the centroid of the ball. This will help to plot the projectile motion. The values obtained from Matlab are in pixels. The coordinates can be converted to meters by multiplying with meter over pixels constant. The presence of the ball in a single frame can be detected by first using the 'bwlabel' function available in Matlab. This function basically searches for connected components of an image. This function takes in a binary image as its input. All the pixels in connected components are given level respectively. The searching for the connected components can be done based on columns, which is from the top-to-bottom scan order. The binary image should contain a bunch of objects that are separated from each other. Pixels that belong to an object are denoted with 1 which indicates TRUE while those pixels that are the background are assigned with 0, which indicates FALSE.

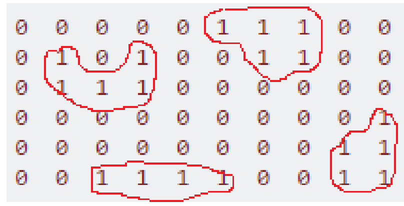

Figure 2.6: ‘bwlabel’ function returns label matrix

There are four objects detected as shown in Figure 2.6. The pixels are lumped into one object when it is connected in a chain by looking at local neighbourhoods. Local neighbourhood implies 8 directions altogether, North, Northeast, East, Southeast, South, Southwest, West, Northwest directions. The output of ‘bwlabel’ function is an integer map. It is based on where each object lies. Each object is assigned with a unique identification [21].

```
[labeledImage, numberOfRegions] = bwlabel(FinalMorph);
if numberOfRegions >= 1
    stats = regionprops(labeledImage, 'BoundingBox', 'Centroid');
```

Figure 2.7: Image processing code for detecting objects in an image

The numbering works in a column basis. Whichever object appears first based on a column will have the first numbering. In this project, ‘bwlabel’ function was used to obtain 2 outputs as shown in Figure 2.7. The first being the integer map and the second indicates number of objects that exist in the image.

Next, ‘regionprops’ function is used to measure a variety of image quantities and features in a black and white image. Centroid and bounding box properties are used in this project. Centroid is used to detect the middle each object. The code shown in Figure 2.8 will calculate the centroids of each of the objects in the image. Centroid returns a vector that specifies the centre of mass of the region. The first element of Centroid is the horizontal coordinate (*x*-

coordinate) of the centre of mass, and the second element is the vertical coordinate (*y*-coordinate). All other elements of Centroid are in order of dimension. Bounding box returns the smallest rectangle containing the region. The width in the x axis and y axis are specified in the output.

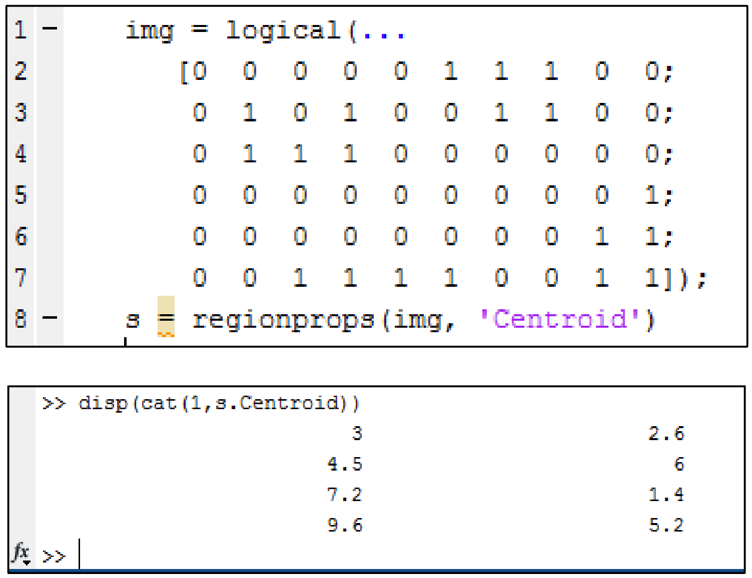

Figure 2.8: Output of a ‘regionprop’ function in Matlab

2.9 MATLAB

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. It can be useful for math and computation, algorithm development, modelling, simulation, and prototyping, data analysis, exploration, and visualization, scientific and engineering graphics, and application development, including Graphical User Interface building.

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows user to solve many technical computing problems. The name MATLAB stands for matrix laboratory. MATLAB features a family of application-specific solutions called toolboxes. In this project the widely used toolbox is the image processing toolbox. There are different sections in MATLAB, mainly the MATLAB language. Secondly is the MATLAB working environment used for developing, managing, debugging, and profiling M-files as shown in Figure 2.9. Next is the handling graphics section used two-dimensional and three-dimensional data visualization as shown in Figure 2.10, image processing, animation, and presentation graphics. MATLAB also has mathematical function library such as the ODE 45 solver which is used in this project.

```
X = [0;0;25;25;0];
Z = [0;2.44;2.44;0;0];
Y = [33.5,33.5,33.5,33.5,33.5];
figure
axis on
xlabel('x-position') % x-axis label
ylabel('y-position') % y-axis label
zlabel('z-position') % z-axis label
plot3( X, Y, Z)
```

Figure 2.9: Sample code for three dimensional plot

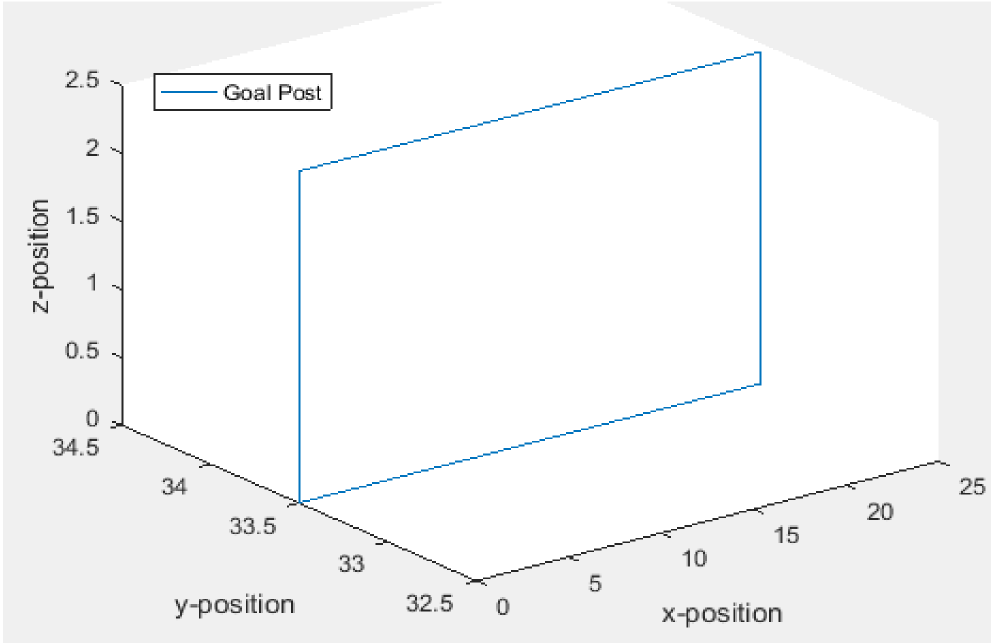

Figure 2.10: Three dimensional plot using Matlab

2.10 Summary

In this chapter, the equations used to construct differential equations have been discussed. During projectile motion, the ball experiences drag and lift force. The equation for drag and lift coefficients are also defined in this chapter. A spinning or revolving object has angular velocity ω. The angular velocity is cause by the Magnus Force. Image processing techniques were introduced in this chapter to further explain process to detect the moving objects in videos.

CHAPTER 3

METHODOLOGY

3.1 Overview

Project flow begins with research on the dynamic system of a table tennis and football when launched. The projectile was simulated using relevant equations. Image processing was conducted to analyse the projectiles. The programming codes are explained in detailed. Results from software are captured and analysis we conducted.

3.2 Description of Steps in the Project Flow

The dissertation workflow is shown in Figure 3.1. Project title is analysed after discussing with supervisor. The project objectives are clearly outlined. The limitations of the project were also identified. Areas and method of research is also discussed in further details. The relevance of the software used in the project was taken into consideration. Past researches and general overview on this project was reviewed. The equations and the derivation process are further analysed to increase understanding on this topic. Wide range of reliable sources is used in order to gain a good grip on the project.

The equations of motion are identified and applied in the simulation. The equations in Appendix A aided in producing the projectile in Matlab. During the simulation, different sets of initial parameters were varied to analyse analyse the projectile. Some of the initial parameters that was frequently manipulated and analysed include the initial velocity, angular velocity on different axes and initial angles of the projectiles.

Image processing was conducted on the two videos. Continuous improvements were made for the code in order to detect the projectile of the ball. Comparison with different threshold values was conducted to study the effect of threshold values on the image being processed.

As mentioned in the project objectives, it is essential to determine if the ball is spinning in order to deduce the resulting projectile. This piece of information will help to mathematically prove projectiles especially in ball games. Award winning projectiles can be further analysed to determine the factors contributing to wildly swerving long-range free kick.

There were two separate analyses done. The first one was for a video recording of a table tennis ball. The video contained the initial projectile of the table tennis. The second part of this research is the analysis on the award winning kick by Faiz Subri. Image processing was carried out for both the videos followed by comparisons with the Matlab model. The Matlab model was developed by considering the forces affecting a projectile.

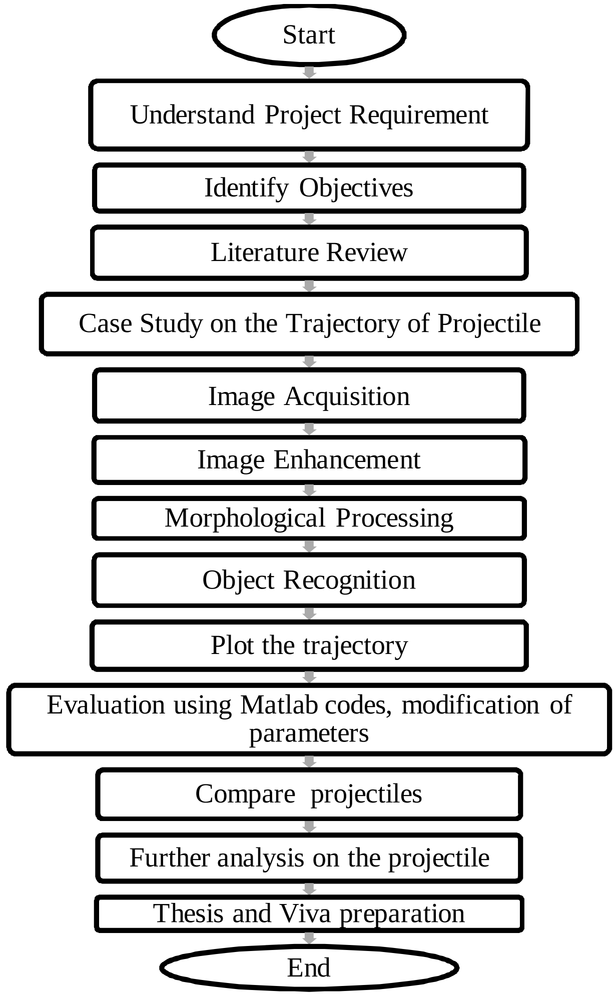

Figure 3.1 Flow chart of the dissertation

3.3 Image Acquisition

Image acquisition was first conducted on the video by separating each frame. VideoReader function in Matlab creates an object to read video data from the file named specified. By assigning this object, the video can be processed based on number of frames in the video.

3.4 Image Enhancement

The images are then converted into 'grayscale' which is a range of gray shades from white to black. Contrast can be applied for an image using the 'imadjust' function. This function