HIGH SPEED IMAGING to DETERMINE THE DYNAMIC of BALL

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HIGH SPEED IMAGING to DETERMINE THE DYNAMIC of BALL

by

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Praise to ALLAH, his majesty for his limitless blessing, and best prayers and peace be unto his best messenger Prophet Muhammad, his pure descendant, and his family and his noble companion.

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PENGIMEJAN KELAJUAN TINGGI UNTUK MENENTUKAN DINAMIK BOLA

ABSTRAK

Tujuan projek ini adalah untuk melakukan pemprosesan imej untuk menganalisa dinamik bola. Pengimejan kelajuan tinggi dan beberapa teknik pemprosesan imej digunakan untuk mengesan pergerakan bola di udara. Pemprosesan imej dapat memberi maklumat dinamik bola seperti kelajuan permulaan bola, ketinggian maximun semasa trajektori bola, kelajuan akhir bola dan sudut pengangkatan. Perisian utama yang terlibat dalam projek ini ialah Matlab, yang digunakan untuk memproses imej untuk video berkelajuan tinggi. Teknik pemprosesan imej digunakan untuk memcerakinkan video kepada beberapa bingkai. Titik tengah bagi setiap bola di setiap bingkai ditentukan. Melalui titik-titik tengah bola ini, kelajuan bola ditentukan.

HIGH SPEED IMAGING TO DETERMINE THE DYNAMICS OF BALLS

ABSTRACT

The purpose of this project is to perform image processing to analyze the dynamics of the ball. The high-speed imaging and some image processing techniques are used to track the moving ball in the air. Image processing can give the dynamics information of the ball such as initial velocity, maximum height during trajectory, final velocity and elevation angle. The main software for this project is MATLAB, which is used to do the image processing for the high-speed video. The image processing technique is used to get   split the video into frames. From the frames, the centroids of the ball are determined, and further analysis is done to get the velocity of the moving ball.

CHAPTER 1

INTRODUCTION

1.1 Research Background

In some sports, ball launchers have been used and quite popular for training purposes. The ball that was shot by the machine involve the physics theory that is known as projectile motion. Projectile motion is when an object is thrown and move along a curved path on the earth surface. This motion only consider gravity as the acting force and neglect the existence of the air resistance [1]. In real situation, air resistance must be considered to get the more precise and accurate calculation. Nowadays, many researches have already included the effect of air to projectile of anything. Image processing have become one of the common method in analyzing a fast-moving object in the recorded in video. In this case, camera equipped with high speed capturing functions allows high resolution tracking of an object in sport games. Before this, the sport uses linesman to determine whether the shuttle was in or out. This judgement is restricted due to the limit of human vision but with the help of video, this problem is solved. The dynamic of the shuttle can be determined through image processing [2].

In many sports, the projectile motion of the balls/shuttle used can be examined by applying image processing technique to the video. All the information from the projectile can be used for researches. With image processing, the parameter such as angular velocity, initial elevation angle and initial velocity of the ball can be determined. All this information is very useful to examine the performance of human or throwing machine.

1.2 Problem statement

Many researches have conducted study on the motion of an object moving in the air. There are four forces that act upon the object which is drag force, lift/magnus force, buoyant force and gravitational force. All these forces influence the trajectory of the object. This project will use the ball throwing machine to get the velocity of the ball. Mathematical analysis can be used to determine the initial parameter of the ball throwing machine such as angular velocity, initial elevation angle and initial velocity. But since there is no exact numerical solution, the calculation of the projectile motion will be not accurate.

There is another way that can be used to study the performance of the ball throwing machine which is image processing. Image processing technique is used to study the projectile of the ball throw by the throwing machine. The high-speed video recorded using a high-speed camera is needed for the study. This technique can analyse the images of moving ball recorded by the camera equipped with high speed capturing function.

1.3 Objectives of Research

The main objectives of this project are as follow:

i. To determine the dynamical projectile parameters that is focusing on the centroid and final velocity of a cricket ball moving in a projectile motion.
ii. To establish a high-speed image processing program to extract the important projectile parameters of a high-speed moving cricket ball.

1.4 Scope of research

This project will be focusing on the image processing techniques used to obtain dynamical parameters of a moving cricket ball in the air by using the high-speed camera which is then saved in the form of video. The video is recorded at the end of the projectile motion using high speed camera. A white colour board is used as the background of the projectile motion to make the object detection become much more accurate. This project only consists of x-plane and z-plane. The existence of y-plane is neglected in this project. The image processing will be performed to the video to determine the centroids of the moving ball. Image processing program is written in MATLAB to get the centroid of the moving ball.

1.5 Thesis Outline

This thesis consists of five chapters. In chapter 1, background of ball throwing machine and projectile motion are discussed. This chapter highlighting the problems of current mathematical analysis of projectile motion and research objective. The chapter ends with the project scope and thesis outline.

Chapter 2 covers the literature review of this thesis. This chapter represent the relation between past works with this project. All the forces acting on the ball moving in projectile motion are discussed in this chapter. This chapter also explained the image processing used to extract the needed information from the video.

Chapter 3 discussed the methodology of the project. It shows the flowchart of how the project is done. Next, the chapter describe how image processing is applied to video in order to obtain the centroid of the moving ball.

Chapter 4 consist of the result of the project. This chapter show the centroid of the moving ball in each frame. The analysis and discussion of the result are presented in this chapter based on the result.

The last chapter which is chapter 5 presented the conclusion of the project. Suggestion for future works and limitation are discussed in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter consists of the literature about the forces that affect the trajectory of projectile and the image processing for a moving ball using high-speed camera. Section 2.2 introduces about trajectory of arbitrarily rotating projectile motion. Section 2.3 explains about the drag force and magnus force. Next in section 2.4 is about the ball detection with high speed imaging. Section 2.5 introduces the ball detection using image procession.

2.2 Trajectory of Arbitrarily Rotating Projectile Motion

Many researches on projectile motion have been conducted for many centuries. It is relatively complicated as it involved both mathematical and physical point of view. The common analytical approach of projectile motion is based on Newton's law which is projectile motion of objects thrown in a vacuum. This simplest approach neglected the effects of the Earth's atmosphere and only take the gravity as the only force. [1]. This approach also ignored the impact of air which can provide important information on dynamics. [3]

In a real-life situation of a projectile motion such as a moving ball, the impact of air resistance cannot be neglected. The trajectory of the spheres is affected by the drag force, lift/Magnus force, buoyant force and gravitational force as illustrated in Figure 2.1.

Figure 2.1 shows the illustration of all forces acted on a moving ball in air.

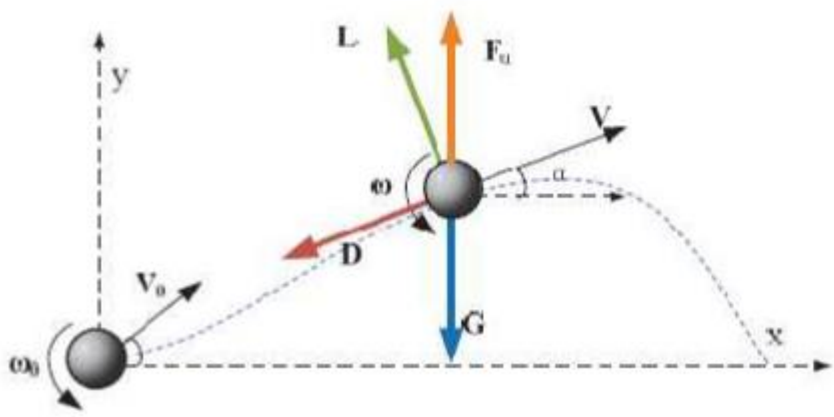

Figure 2.1 Force and Motion Analysis [3]

where *L* is lift or Magnus force, F_u is the buoyant force, *D* is the drag force, *G*= gravitational force, *w* is the angular velocity and *V* is the velocity of the ball. Based on the illustration in Figure 2.1, all the forces mentioned are important for a moving ball to drive in a projectile motion.

2.3 Drag Force and Magnus Force

When a ball is thrown in the air at an arbitrary angle, it will encounter air resistance. This air resistance which is also known as drag force is resulted in the opposite direction of the movement of the ball. Figure 2.2 shows the illustration of a flying ball with its instantaneous velocity, *v* and the drag force, $F_{D.}$ In the real situation, the batted ball may be encountered in two situations, spin backward (backspin) and spin forwards (topspin). This spinning is quantified as angular velocity, ω. The spinning ball with angular velocity vector is considered perpendicular to the vertical plane, hence for the back-spin ball it orients its angular velocity parallel to the ground and outward to the vertical plane. Conversely for the topspin ball, it orients its angular velocity parallel and inwards to the ground [4]. Figure 2.2 shows the flying ball in back-spinning situation.

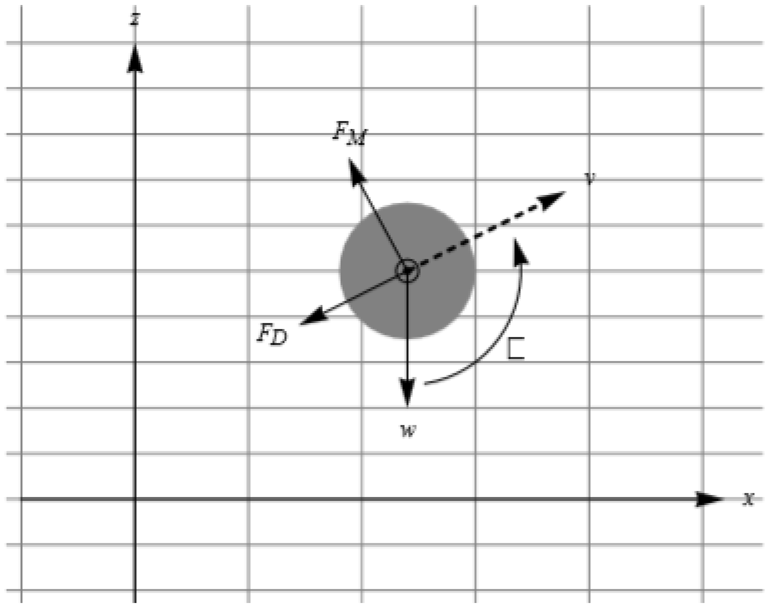

Figure 2.2 The profile of flying ball in backspin situation [4]

Based on Figure 2.2, the dot at the centre of the ball represents the head of angular velocity, ω emerging the xz-plane. In this situation, the spinning ball is subjected to a spin-dependent force, namely the Magnus force, F_M. The scenario given in Figure 2.2 is a backspin ball (counter-clockwise rotation) with a vector piercing outward and perpendicular to the vertical xz-plane. The dashed line in the instantaneous velocity, *v* of the ball and solid arrows are the active forces which are: Magnus force, F_M, the Drag force, F_D, and the weight, *W*.

Based on the research documented by Garry Robinson and Ian Robinson [5], the magnitude of the Drag force is written as:

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

where ρ is the density of air, *A* is the cross-sectional area of the spherical projectile, C_D is the drag coefficient and *V* is the projectile's velocity relative to the air. The Drag coefficient, C_D is dependent on V but remains constant approximately 0.45 for smooth spheres. Transforming in the vector form, this equation is written as:

$$\overrightarrow{F_D} = -\frac{1}{2}\rho A C_D V^2 . \vec{V} \tag{2.2}$$

For the Magnus force, F_L the formula is written as:

$$F_L = \overrightarrow{F_L} = \frac{1}{2}\rho A C_L V^2 \tag{2.3}$$

where ρ is the density of air, A is the cross-sectional area of the spherical projectile, C_L is the lift coefficient and V is the projectile's velocity relative to the air. The direction of Magnus force is represented by $\vec{w} \times \vec{V}$ and vary as $\sin\theta$ where θ is the angle between $\vec{w}$ and $\vec{V}$. This angle is varying between 0° to 180° [5]. The Magnus or lift force also can be represented in vector form as below:

$$\overrightarrow{F_L} = \frac{1}{2}\rho A C_L V^2 \sin\theta . \hat{n} \tag{2.4}$$

where $\hat{n}$ is a unit vector in the direction of $\vec{w} \times \vec{V}$ and is express as:

$$\hat{n} = \frac{\vec{w} \times \vec{V}}{\vec{w} \times \vec{V}} \tag{2.5}$$

2.4 Ball Detection With High Speed Imaging

Today's advanced technologies have produced many solutions that allow objects to be tracked with high resolution. High-speed tracking technologies have been used in sports such as tennis, football and cricket around the world. In 1960s, Bayes and Scott used a Polaroid camera and a stroboscope to track the movement of the balls. However, they did not base their results on this setup probably due to the poor accuracy of the cameras at that time [6]. Alciatore used high-speed video capture mainly to visualize the dynamics in the game of pool and used infrared imaging to visualize the collision point, but he did not analyze the images to extract the physical parameters involved on dynamics [6]. Based on study of golf ball simulation done by [7] the algorithm is used to detect the initial position of the ball. To generate a real path trajectory of the ball, a top camera system is installed on the ceiling to detect the initial position of the ball. Figure 2.3 shows the golf detection algorithm and detection result.

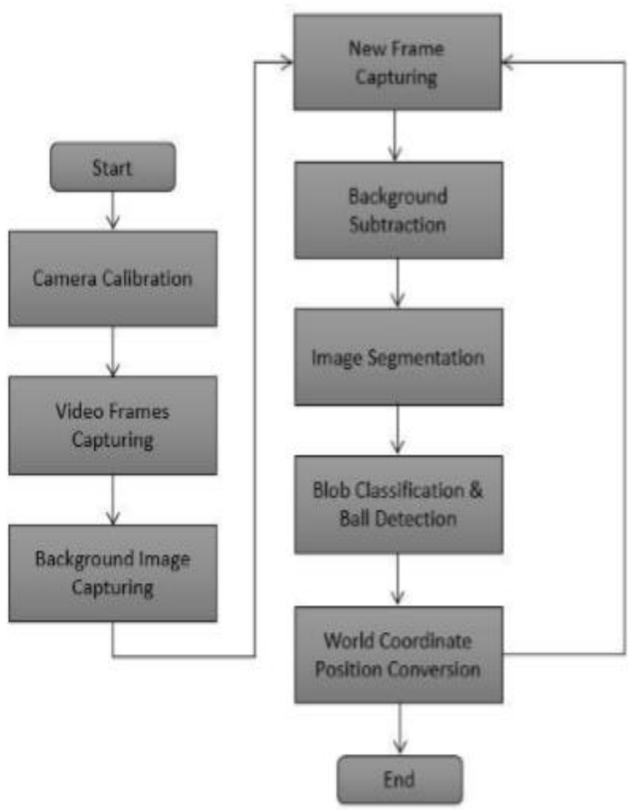

Figure 2.3 (a) Algorithm for image detection [7]

In this algorithm, frames are captured from golf course first. Then the object is detected in each frame based on background subtraction and image segmentation. Non-ball shapes are ignored up on golf ball features and object classification. Then finally the ball position in the world coordinate is determined by using camera calibration. In the study done by previous work [6], the camera with capturing speed that capable to capture up to 1000 frames per second able give a good result in determining the dynamics involved in snooker, hence this type of cameras with this speed of capturing is suitable in determining the detection of moving ball.

2.5 Object Detection using Image Processing

When doing something with image processing, object detection is one of the important thing that need to be concern. Object detection technique will detect and extracts the object from noisy image. Object detection involve the theories of mathematical morphology that involve dilation and erosion. Dilation means adding pixel to the boundaries of an image, while erosion remove the pixel from the boundaries of an image.

The dilation of an image X by element B is defined as $X \oplus B$.

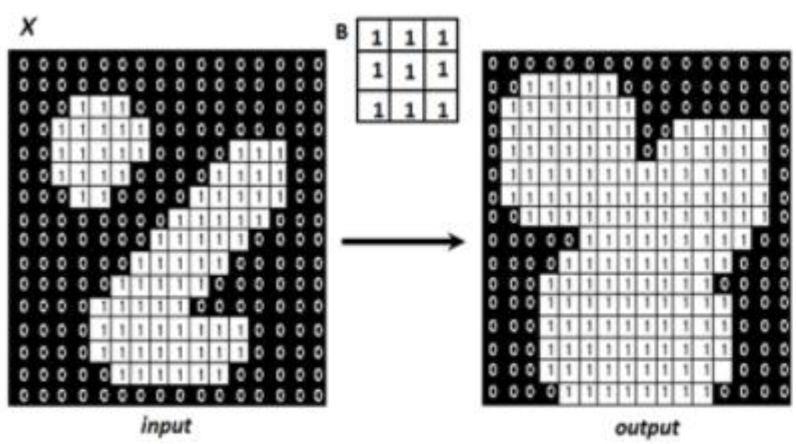

Figure 2.4: Effect of dilation using a 3x3 square structural element *B* [8]

Each time the origin of the structuring element (B) touches a binary 1-pixel (X), the entire translated structuring element shape is ORed to the output image which has been initialized to all zero. Figure 2.5 shows the effect of dilation using a structuring element [8]. The dilation operation enlarges the object in the image.

While the erosion of image X by element B is defined as X ⊖ B. The structuring element B will be scanned over the image. At each position where every 1-pixel of the structuring element (B) covers a 1-pixel of the binary image (X), the binary image pixel corresponding to the origin of the structuring element is ORed to the output image [9]. Figure 2.6 shows the effect of erosion using a structuring element [8]. The erosion function decreases the size of object.

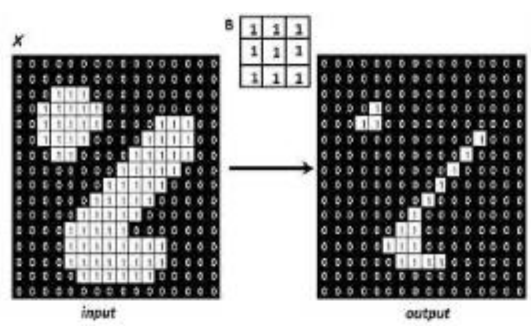

Figure 2.5: Effect of Erosion using a 3x3 square structural element *B* [8]

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter will discuss about the methodology of this project. The first thing to be begin with will be the flow chart. The flow chart will show step by step carried out throughout the project and act as a guideline in preventing off-track cases from happening. All the steps will be explained in detail on how to achieve the project objectives. Figure 3.1 portrays the flow chart established in giving a whole idea of how this project will be implemented. Next, the software and hardware involve in this project is presented. The flowchart of the image processing program is explained in detailed in this chapter.

3.2 Project Flow

The overall project implementation methodology is represented in flow chart below

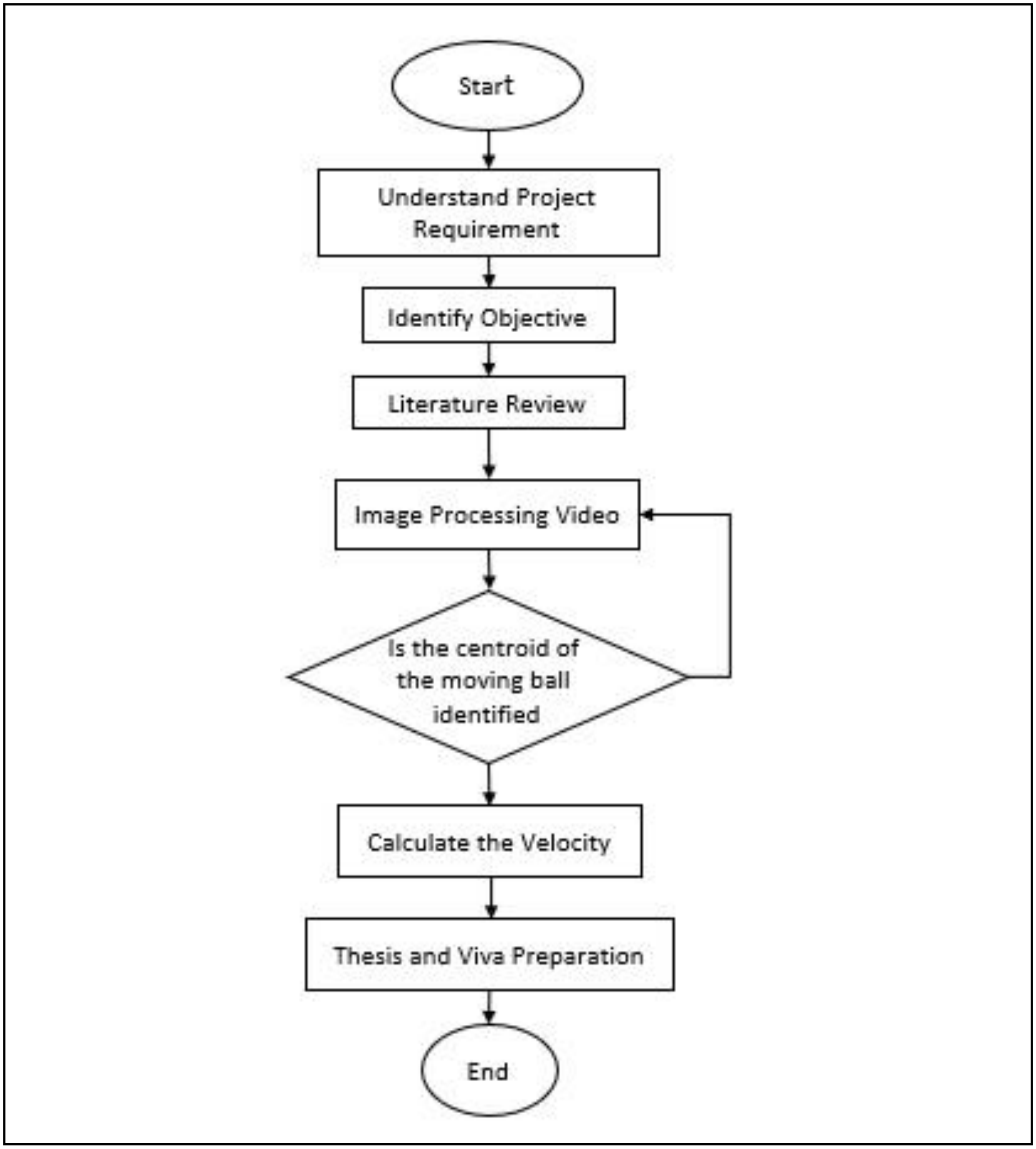

Figure 3.1: Flow chart of the project

3.2.1 Description of Steps

Discussion with lecturer is done to determine the tittle and objectives for this project. The important requirements are jotted down to help in searching information in later step.

In order to get an overview of the topic and understand past studies that had been conducted on the relevant field, literatures and journals from library and internet are reviewed. From the studies, the image processing techniques are investigated and the theories of locating an object in a noisy image are determined.

A test is set up to record high speed video of a cricket ball moving in air in which a ball throwing machine and a camera that able to capture video up to 1000 frames per second are used in that test. Next, the centroid of the cricket ball moving in air from a high-speed video is computed by using an image processing program written in MATLAB. The centroids of the cricket ball are analyses and the velocity of the cricket ball is determined. Lastly, a complete and well-ordered thesis is written, and presentation slides are prepared for Viva session.

3.3 System Description

The main point in this section cover the dynamic system possessed by the moving table cricket which obtained from the high-speed video using image processing programming established via MATLAB. First, the forces acting on the ball are discussed where the forces play such big role in projectile motion of the ball itself and next the characteristics of the ball's projectile motion is the figured out.

3.3.1 Dynamic System in Projectile Motion

The motion of a spinning cricket ball in the air is due to the forces that acted on the ball. The forces comprise of gravitational force F_g, buoyant force F_u, drag force $\vec{F}_D$ and lift or Magnus force $\vec{F}_L$. The formula of the gravitational force and buoyant force are shown as follow:

$$F_g = mg \tag{3.1}$$

$$F_u = \rho g V = \frac{1}{6}\pi\rho d^3 g \tag{3.2}$$

where m is the mass of ball, g is the acceleration due to gravity, ρ is density of air, V is the volume of ball and d is the diameter of ball.

The vector form of the drag force is given by

$$\vec{F}_D = -\frac{1}{2}\rho A C_D V.\vec{V} \tag{3.3}$$

where ρ is the air density, A is the cross-sectional area of the spherical projectile, C_D is the (dimensionless) drag coefficient =0.45, V is the magnitude of the projectile's velocity and $\vec{V}$ is the projectile's velocity in the form of vector.

The vector form of the lift of Magnus force is

$$\vec{F}_L = \frac{1}{2}\rho A C_L V^2 \sin\theta \,.\, \hat{n} \tag{3.4}$$

where ρ is the air density, A is the cross-sectional area of the spherical projectile, V is the projectile's velocity relative to the air, Θ is the angle between $\vec{w}$ and $\vec{V}$ which varies from 0° to 180°. C_L is the (dimensionless) lift coefficient which is in general function of w. Equation of C_L is

$$C_L = 3.19 \times 10^{-1} \, [1- \exp -2.48 \times 10^{-3} w] \tag{3.5}$$

$\hat{n}$ is a unit vector in the direction of $\vec{w} \times \vec{V}$ The equation of $\hat{n}$ is equal to

$$\hat{n} = \frac{\vec{w} \times \vec{V}}{\vec{w} \times \vec{V}} \tag{3.6}$$

Then, sin Θ can be derived by using formula of cross product

$$\vec{w} \times \vec{V} = wV \sin\theta \, \frac{\vec{w} \times \vec{V}}{\vec{w} \times \vec{V}} \tag{3.7}$$

$$\sin\theta = \frac{\vec{w} \times \vec{V}}{\vec{w} \times \vec{V}} \tag{3.8}$$

Equation of lift or Magnus force can be rewritten as

$$\vec{F}_L = \frac{1}{2}\rho A C_L V (\frac{\vec{w} \times \vec{V}}{w}) \tag{3.9}$$

For better understanding, the forces acting on the moving cricket ball should be illustrated in a complete figure. Figure 3.2 portrays the schematic of the forces acting on the ball.

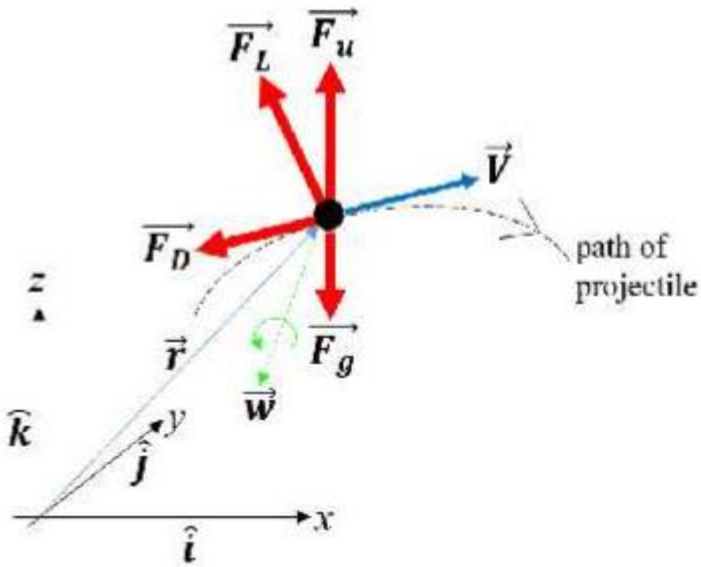

Figure 3.2: Schematic Diagram of the Four Forces Acting on the Projectile

The magnitude of velocity V and magnitude of angular velocity *w* in the equation can be expressed as

$$V = \overline{(V_x^2 + V_y^2 + V_z^2)} \tag{3.10}$$

$$w = \overline{(w_x^2 + w_y^2 + w_z^2)} \tag{3.11}$$

where V_x, V_y and V_z are the velocity of the projectile in x, y and z direction whereas w_x, w_y and w_z are the angular velocity in x, y, z direction.

3.3.2 Dynamic System Extracted from High Speed Video

The important dynamic characteristics of the cricket ball moving in the air can be obtained by implementing such a high-speed imaging technique. As mentioned in previously, the cricket ball threw by ball throwing machine is moving in two axes (*x* and *z* axis) and limited to be constant in *y* axis. Camera is used to capture the video of the moving cricket ball and by using the image processing program, the position and velocity of the ball can be determined. Figure 3.3 shows the illustration of projectile motion of a moving cricket ball in the high-speed video.

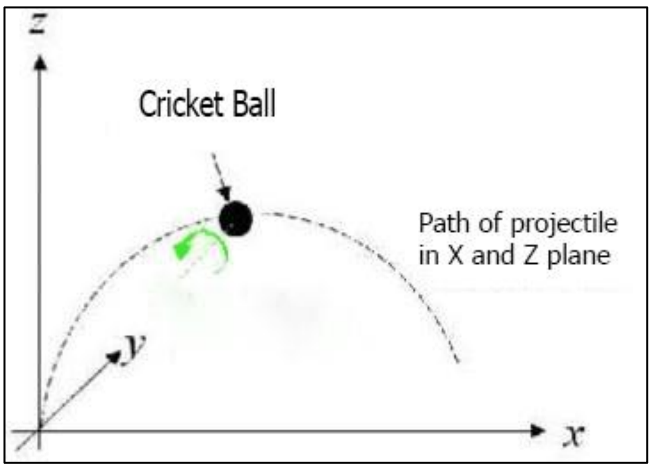

Figure 3.3: Moving Direction of Cricket Ball in Video

3.4 Software

In this project, image processing program is established by using computer software which is MATLAB programming. Then, Window Movie Maker is used to edit the high-speed video which had been recorded using Fujifilm FinePix HS10 and then the video is processed by using image processing program to obtain dynamic characteristics of the ball.

3.4.1 MATLAB

MATLAB is a numerical computing environment that allows matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces and interfacing with programs in other languages. The simulation of the trajectory of projectile can be done by programming the related equations in MATLAB. Not only that, the Image Processing Toolbox in MATLAB extend the capability of the MATLAB numeric computing environment. The toolbox supports a large extend of image processing operations which comprise of spatial image transformations, morphological operations, neighborhood and block operations, linear filtering and filter design, transforms, image analysis and enhancement, image registration and so on.

3.4.1(a) Image Processing

By using MATLAB, an image processing program is written to execute the following operations. The program is attached in Appendix B. The high-speed-moving cricket ball is recorded by using Fujifilm FinePix HS10 in which the video is split into image frames for interpreted purpose. From frame one, the image is converted into gray scale image and then transformed into binary image through appropriate threshold value of image intensity. To detect the existence of the ball in the image, the technique of morphological closing and opening is implemented as an object detection method. These processes will keep repeating until the ball has finally been detected. This operation will be followed by determining the centroid and final velocity of the ball.

For this purpose, a function from the MATLAB Image Processing Toolbox called *regionprops* is used. The location of the ball in that specific frame is set as the initial point of the trajectory of projectile. The image processing program repeat the processes to gather all the values of ball centroid in pixel for the following frames. A calibration process is then applied to obtain the real-world coordinate of the cricket ball centroid in such a way that the calibration process translates the ball centroid in pixel to real world coordinate. A trajectory of the moving table tennis ball can be plotted from the gathered coordinates of the ball centroid. Figure 3.4 shows the flow chart of the image processing program.

Precisely, calibration process calculates the ratio of the change in real world coordinate to one pixel in the image. The moving distance of the object in the images is determined in terms of pixel values in horizontal direction. Then, the pixel values are multiplied with the ratio to acquire the moving distance in real world coordinate.

Initially, the ratio is obtained before conducting the test. The Fujifilm HS10 camera position, zoom value of the camera lens and the ball throwing machine position are set constant in that particular test. The camera need to be set perpendicularly to 2D-plane where the cricket ball moves along and after that a high-speed video of the moving ball is recorded.

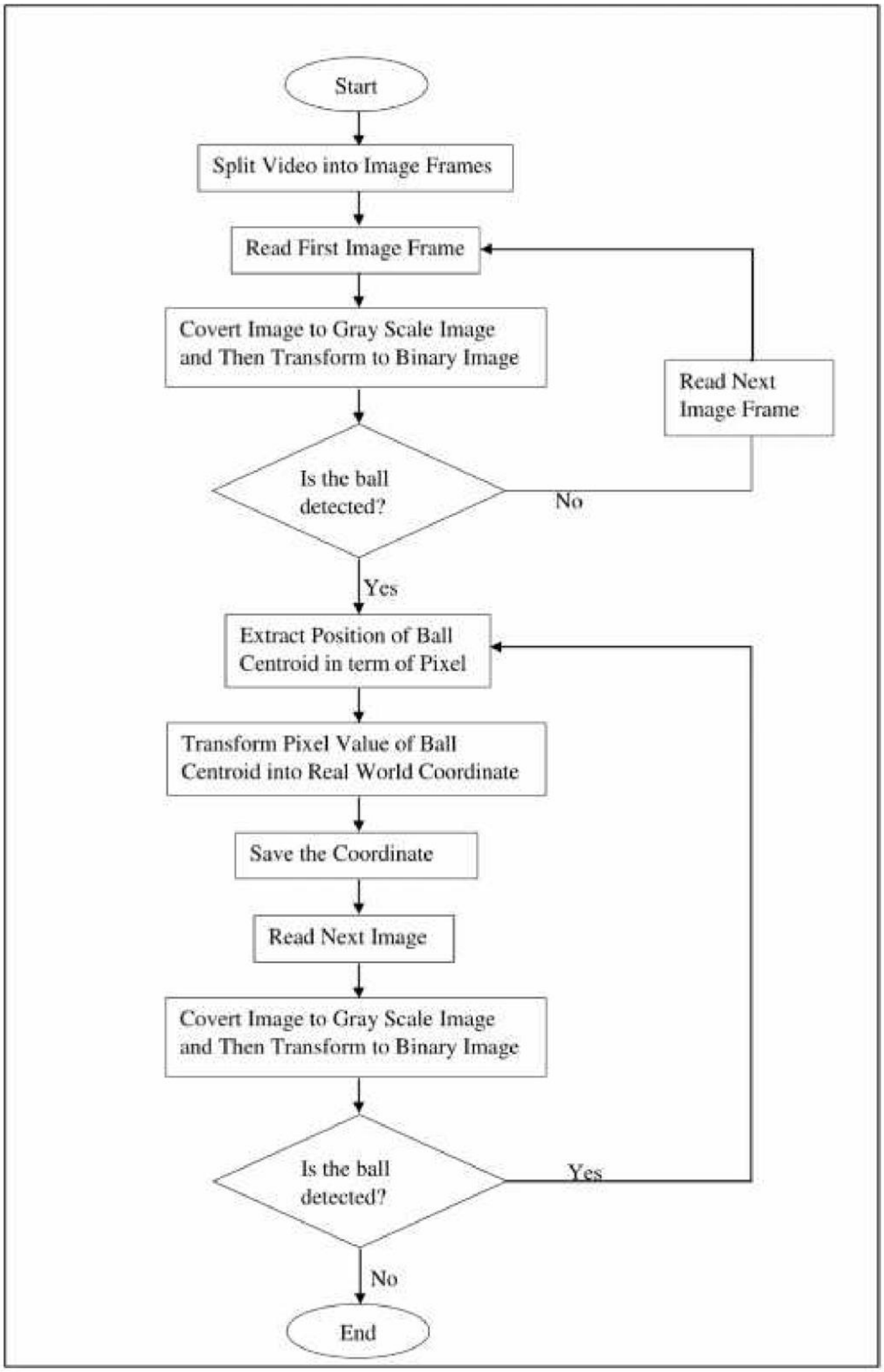

Figure 3.4: Flow Chart of Image Processing Program

The real-world horizontal distance of the ball on the initial point of the board to the ending point of the board is measured by using measuring tape. By doing image analysis, the corresponding distance in term of pixel values can be acquired. To obtain the ratio of the change in the real-world coordinate to one pixel in the image in horizontal direction, division operation on values of the real-world distance to the corresponding pixel values is applied.

$$Ratio = \frac{Length\ of\ board}{Width\ of\ Video} = \frac{50\ cm}{640\ pixel} = 0.07813\ cm/pixel$$

The ratio should be recalculated once one of the settings among the camera position, the zoom in value of the camera lens and the ball throwing machine position is changed. After computing the positions of the cricket ball in real world coordinate, the velocities of the moving cricket ball in air are obtained by computing the successive distance between the ball centroids from the video.

3.4.2 ***Regionprops*** Function

Regionprops function is the function in MATLAB that can be used to measure the properties of images. It is a very useful function that commonly used. *Regionprops* measures a variety of image quantities and features in a black and white image. In this project, all image frames are turned to binary to get the black and white image. In this project, the properties that will be determined is the centroid. This function will give the (x,y) location of where the middle of each object is located.

3.4.3 Windows Movie Maker

Windows Movie Maker is a video editing software by Microsoft that is capable in viewing a video frame by frame. The high-speed video recorded using Fujifilm FinePix HS10 is edited using Windows Movie Maker before it is processed using image processing program. The video of the cricket ball moving in the air is trimmed to shorten the video in which the parts before the ball is threw from the ball throwing machine and the video part after the ball exits the camera capture area are removed. The purpose is to reduce the number of frames in the video so that the processing speed of the image processing program can be increased.

3.5 Hardware

The hardware involved in this project are the equipment used to record high-speed video of a cricket ball moving in air. Test is set up by using this equipment that comprises of camera, ball throwing machine and cricket ball.

3.5.1 Camera

The camera used in capturing high speed video in this project is Fujifilm FinePix HS10 which is capable in capturing high speed video up to 1000 frames per second in resolution of 224 × 64. The camera succeeded in capturing the projectile motion of the cricket ball. This camera is placed perpendicularly to the 2D-plane where the cricket ball is thrown from the ball throwing machine.

3.5.2 Ball Throwing Machine

The ball throwing machine is used in this project with the practicing advanced strokes of topspin and backspin settings. The rotational direction of the cricket ball threw from the machine is adjustable. The machine uses two rotating rollers as a mechanical launcher to throw the ball.

3.5.3 Cricket Ball

The diameter and the weight of the cricket ball are measured with Vernier Caliper and weighing machine respectively. To ease the process, all the tests carried out in this project are using the same cricket ball so that the parameters of the table tennis ball are constant. The diameter of the cricket ball used in this project is 72.28mm and the weight of the ball is 161.9g.