


**A METHOD TO DETERMINE SIZE OF OBJECT FROM  
360 DEGREE CCTV**

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**A THESIS SUBMITTED IN PARTIAL FULFILLMENT  
OF THE REQUIRMENTS FOR THE DEGREE OF  
MASTER OF ENGINEERING (COMPUTER ENGINEERING)  
FACULTY OF GRADUATE STUDIES  
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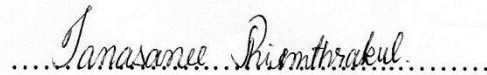
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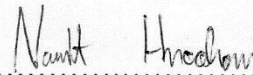
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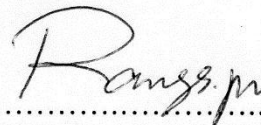


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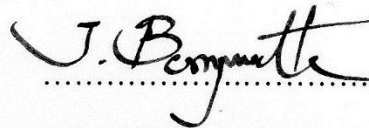


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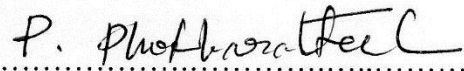
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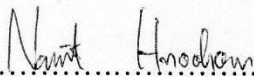
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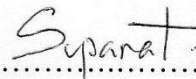
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TANASANEE PHIENTHRAKUL, Ph.D., NARIT HNOOHOM, Ph. D.****ABSTRACT**

The recent digital imaging technologies enable a new way to capture spherical image which allow capturing 360-degree view simultaneously. This technology has been made available and has an increasing popularity in public. Therefore, to accept such digital images as forensic evidences, some studies are needed.

In practice, a spherical image is stored in an image file such as JPEG. However, the geometrical relationship between adjacent pixels is based on polar coordination system which differs from the projection in Cartesian coordinate system in normal photography. As a result, upper and lower parts of the spherical image are compressed and highly distorted. This research focused on spherical-cylindrical transformation and the projection onto a virtual plane to correct the image geometry.

This study proposed a mathematical model to transform spherical image into cylindrical image to remedy the image distortion caused by the compression of pixels at the top and bottom of the image and transform cylindrical into a flat image to remedy distortion of the image pixels in the horizontal direction using Matlab software. In addition, simulation and photographed image using 360-degree camera were tested.

The experiment confirmed that the error of estimated height and width of objects at a distance less than 1.2 meters is within 5 percent and the result images were more suitable to be used for forensic identification.

**KEY WORDS: 360-DEGREE CAMERA / SPHERICAL / DIGITAL IMAGE****FORENSICS**

43 pages

วิธีการพิสูจน์ทราบขนาดของวัตถุจากภาพถ่ายกล้องวงจรปิดแบบ 360 องศา

A METHOD TO DETERMINE SIZE OF OBJECT FROM 360 DEGREE CCTV

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#### บทคัดย่อ

เทคโนโลยีการถ่ายภาพในปัจจุบัน เปิดโอกาสให้การเก็บภาพแบบทรงกลม (Spherical Image) ที่เก็บแบบ 360 องศา สามารถกระทำได้และมีใช้งานแพร่หลายเพิ่มขึ้น ส่งผลให้งานพิสูจน์ตัวตนและเอกลักษณ์ของบุคคลและวัตถุต้องสงสัยจากข้อมูลภาพ เพื่อใช้ในกระบวนการยุติธรรมมีความจำเป็นต้องทำการศึกษาเพื่อที่จะใช้เป็นหลักฐานภาพถ่ายแบบดิจิทัลได้

ในทางปฏิบัติข้อมูลภาพแบบทรงกลมจะถูกเก็บไว้ในไฟล์ในลักษณะเดียวกับข้อมูลภาพทั่วไปมีลักษณะเป็นข้อมูลแบบ 2 มิติ แต่เนื่องจากพิกเซลแต่ละพิกเซลนั้นมีพื้นฐานมาจากระบบพิกัดเชิงขั้ว (Polar Coordinate System) ซึ่งแตกต่างกับการฉายภาพในระบบพิกัดฉาก (Cartesian Coordinate System) ของกล้องถ่ายภาพทั่วไป จึงทำให้ส่วนบนและส่วนล่างของภาพถูกบีบอัดและสูญเสียสัดส่วนที่ถูกต้องไป ในการศึกษาครั้งนี้ จะเน้นการแปลงภาพจากทรงกลม ไปสู่ภาพแบบทรงกระบอก และทำการฉายบนระนาบสมมติ

เราได้เสนอแบบจำลองทางคณิตศาสตร์เพื่อเปลี่ยนรูปทรงกลมให้เป็นภาพทรงกระบอกเพื่อแก้ไขความผิดเพี้ยนของภาพที่เกิดจากการบีบอัดพิกเซลที่ด้านบนและด้านล่างของภาพและแปลงรูปทรงกระบอกให้กลายเป็นภาพแบนเพื่อแก้ไขความผิดเพี้ยนของพิกเซลภาพในแนวนอนโดยใช้ซอฟต์แวร์ Matlab โดยการจำลองสถานการณ์และถ่ายภาพด้วยกล้อง 360 องศา และนำภาพที่ได้มาทำการทดลอง

จากการทดลองพบว่า ความแม่นยำในการวัดความสูงและความกว้างของวัตถุ มีค่าความคลาดเคลื่อนน้อยกว่า 5 เปอร์เซ็นต์ที่ระยะทางไม่เกิน 1.2 เมตร และภาพผลลัพธ์ที่ได้มีความเหมาะสมมากขึ้นในการใช้ในกระบวนการพิสูจน์ตัวตน

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# CHAPTER I

## INTRODUCTION

### 1.1 Background and Motivation

Closed-Circuit Television (CCTV) has been widely adopted as a tool for video surveillance and security. There have been several usages in many places both indoor and outdoor. The current trend of the usage of such devices is on the rise especially in public places such as government building, shop, restaurant, automobile, etc. Not only the CCTV can provide some visual evidences for a crime, but it can also give the public with a positive sense of security.

There has been an increasing number of evidences produced by CCTV that are used in the court of justice. The CCTV system normally consists of two parts: cameras and recorders. A camera is a sensory device that transforms a spatial light information into electrical signals that can be displayed as a time-series of two dimensional data. A recorder is a device that captures the signals from the camera and transform them into a suitable format before recording on a designate media. Information produced by camera are considered very large when compared with the current storage technology. Therefore, all recorders employ some lossy compression techniques to improve recording time. A lossy compression implies that the original and the reconstructed images are inevitably different. Some common artifacts from lossy compression are blocky effect, blur edge, discoloration, etc.

Some cameras are equipped with a special lens such as telescopic lens, wide angle lens, fisheye lens, etc. These lenses allow the Field of View (FoV) of the camera to be narrow or wide to suit the requirements of the area under surveillance. In Thailand, many high security government facilities deploy camera that can make 360-degree view of the surrounding area when mounted underneath the ceiling. The main advantage of this camera is that it provide large coverage area. Therefore, fewer camera installations are needed when it is deployed in very large facilities. The main disadvantage is that the images produced by the camera have an inherited geometric

distortion. Facial features and length of physical object cannot be measured directly. As a result, identification of a person based on the Facial Identification Scientific Working Group (FISWG) cannot be performed effectively.

In Thailand, video evidences can be used in the court of justice with statistical supports from facial analysis to identify subjects in the scene. At present, the best practice uses Facial Image Comparison Feature. Consequently, the process of facial identification and measuring physical dimension of object can be assessed with a standard method.

## **1.2 Research Objectives**

1.2.1 Measuring the object of interest that appear in the photo 360-degrees.

1.2.2 Develop a mathematical model for the optical flow of the 360-degree camera.

1.2.3 Validate the mathematical model and perform accuracy assessment for the distortion correction algorithm.

## **1.3 Scope of Research**

In this research, some limitations and assumptions are needed in order to facilitate the mathematical modeling and conducting the experiments. Details are as follows,

1.3.1 Image from recorded by a 360-degree camera which form a spherical image in JPEG format.

1.3.2 One mathematical modeling for the scenario of the working space for image capturing which will include,

- One 360-degree camera mounting on a tripod of known distance between two legs is used as an image source.

- The perpendicular distance,  $z$ , of the camera to an object is less than 120 centimeters.

- The parallel distance,  $x$ , is within  $\pm 120$  centimeters.

- The height of the camera is between 120 to 180 centimeters.
- The height of the object is 180 cm.

1.3.3 Images are captured under natural light condition in outdoor environment.

## **1.4 Expected Results**

1.4.1 An algorithm that converts a spherical image to a flat image. The object from the flat image is better proportion than the 360-degree image and close to the original object.

1.4.2 The height of the object can be accurately estimated from the 360-degree image through the developed mathematical model.

1.4.3 A flat image that is generated by the spherical-to-flat transformation can be used for facial identification.

## **1.5 Significance of the study**

1.5.1 Measuring has been a crucial part in establishing identity of suspects. The ability to perform this measuring from image evidences will be of great benefits to the law enforcement and justice. The 360-degree imaging device is getting more popular based on the fact that it can capture all the perceivable angles in one image.

1.5.2 The drawback of the 360-degree image is that if the object presents at very low or very high pitch angle, the pixel information is more compressed. As a result, the object will appear distorted. The flat image will provide the way to reconstruct the object appearance to its original proportion which allow will accurate facial identification of the suspects.

## **CHAPTER II**

### **LITERATURE REVIEW**

#### **2.1 Methods to Enhanced Image Quality from CCTV**

Many electronic and digital devices, nowadays, contain some form of capabilities to store data for various purposes. Those purposes can be for the primary functions such as in computer application where inputs is received and processed to produce outputs. The inputs, outputs, intermediate data can be stored in the device itself as part of the services. For some application, data produced by the primary functionality may not be store on the device itself, but some kind of engineering data such as maintenance logs, debugging information and etc. are stored on the device for the engineering purposes. Both types of data on the device can be used as digital evidences in the investigation.

Digital devices such as cellphones, computers, tablets and digital cameras are common sources of digital evidences in the court of law. These devices produce and store data as the primary function of their services. Digital evidences have recently been accepted in crime investigation in Thailand. [1] Not only it raises the public attention and awareness, but also creates a new field of research in digital forensic and investigation. The digital forensic and investigation are the pursuing of truth based on digital evidences. Therefore, digital evidences are the key to resolve the case and no further questions needed be answered. As a result, the credential of the digital evidences and the correctness of analysis are crucial to establish relevancy of such evidences to the case in the court of law. [2]

#### **2.2 Digital Image Forensics**

Digital evidence such as image must be verified and validated to ensure the authenticity of the image which implies that the source can be identified and no

tampering applies. Image analysis from CCTV camera mainly involves the following procedures,

- Shadow Analysis

When light shines on an object, it illuminates the object. Photon from the illumination arrive at the imaging sensor and produce pixel information. Shadow is the absence of light (photon) which occurs behind the object where the light cannot reach. The shadow analysis is the process to analyze and confirm that shadows that occur on the image are consistent with physics of light.

- Light Analysis

In many circumstances, lights may come from multiple sources. The illumination effects on each area of the image must be consistent with the location of the light sources. The light analysis aims to detect the areas that has different illumination effect which is the result of digital tampering.

- Lens Distortion Analysis

Every camera has a lens which is a piece of transparent medium that allow the light to bend toward the focal point. Each lens come with its own imperfection such as abnormal curvature, dust, scratches, etc. This analysis detects such imperfection and compute the signature of the lens. Images that are produced from the same camera will produce the same signature. Therefore, the linkage between images and the camera can be established.

- Vanishing Line Analysis

Perspective effect result in near objects appearing larger than far objects. The object at the distance approach infinity appears vanished. In general, all objects at the horizon will appear too small to see which can be shown as a vanishing line. If the object appearance are not geometrically complied with the vanishing line of the image, this could be the sign of digital tampering

- CCD Defect Analysis

Similar to the lens distortion analysis, the CCD is an imaging sensor which contains some imperfections from both the production and the usage. This provide the linkage between the images and the camera.

Forensic image analysis aims to extract the crucial piece of information from the authentic images. The procedures may involve. [3]

- Image Enhancement

This process uses image processing techniques to improve the intricate detail of the region of interest inside the image. The purpose is for a better visualization. It may involve contrast and brightness enhancement, noise reduction, etc. Most image processing operations will perform similarly throughout the image.

- Biometric Identification

This process is used to identify an individual based on parameters that can be extracted from the image. Parameters may include pixel information, shape, color, distance between two points, etc. The extracted parameter are computed to provide supporting statistics that establish a distinct identity of the individual.

- Image Metrology (Photogrammetry)

This involve measuring of certain part of the image that appear to contain crucial piece of information. The measure unit may be in pixel on the image. If the focal length of the camera and the distance from the object is known, the measuring unit in meter can be estimated.

- Image Authentication

This process is to verify and validate that the image is authentic. The recent advance in computer graphic technology and tools enable digital image tampering to the detection level of human eyes. Several aforementioned image analyses are used for tampering detection. Once the image is proved to be authentic, it can be used as a digital evidence.

- Three-Dimensional (3D) Measurement

An image is a 2D information capture from the viewing angle of a camera. The transformation from a 3D environment into a 2D image is a process called projection. The projection is performed naturally based on perspective effect of the optical setup of the camera's lens. Additional image capturing parameters must be known in order to compensate of the missing dimension. Normally, mathematical modelling of the 3D scene is required in order to provide sufficient accuracy for the measurement.

### **2.2.1 Photogrammetry**

Digital imaging is the process to transform photon into digital information. The basic unit is a pixel which represent a single ray of light from the object. Most of the digital imaging sensors produce two dimensional outputs which form an image. Each pixel in the two dimensional output are separated into red, green, and blue and generally quantized into 8-bit per color. The process to acquire the image information into a system is called image capturing. Some factors that may impact the quality of the images are,

- Incompatible formats which are the result from proprietary file system and format of specific imaging system. In many cases, the system may provide some kinds of export capability to a well-known file format such as TIFF, JPEG, etc. In some close system, there is no such file export capability. The images are acquired through screen capturing that, in the worst case, a camera may be used to take picture of the screen.

- Poor resolution and lighting conditions which result in low quality picture. Sufficient amount of the pixels yield enough details for further processing. If camera sensors does not provide enough resolution, it will be impossible to establish sufficient identity of the object in the scene. The lighting conditions is another factor that helps to improve the visualization. The pixel information need to have enough photons to establish the intensity. Too much photons may also saturate the sensor. Therefore, to produce a good quality image, the lighting condition must have sufficient brightness and contrast that allows the object to be identified.

- Compression artifacts which is inhered from the image file format. Two dimensional information such as image are normally large in size. One image may be a few million bytes, but having 30 images per second for a few months will require trillion of bytes in the storage. Therefore, many compression algorithms are used to reduce the amount of the storage required for imaging applications such as Closed-Circuit TeleVision (CCTV).

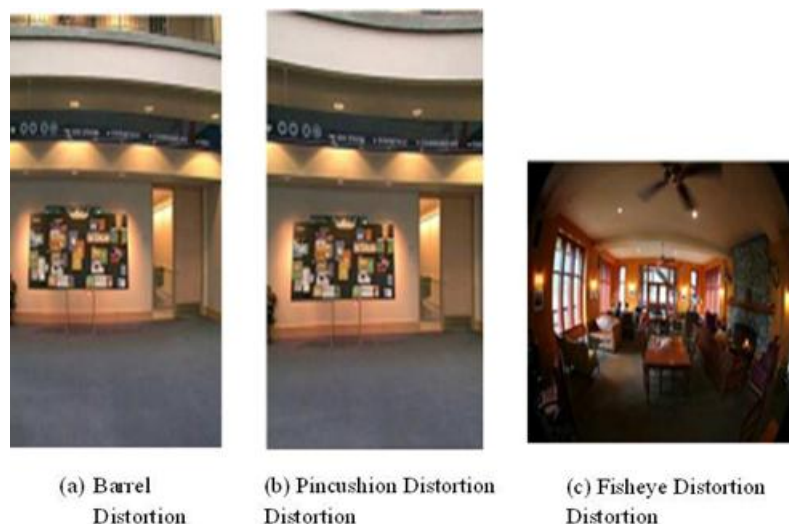
- Video archive environment may have impact to the availability of the images. In some cases, CCTV archive are poorly maintained. As a result, technical failure may happen both during the capturing and retrieval of the images. High availability system design may be deploy to overcome technical failure, but

improvement on the environment may contribute to higher availability without significantly incurring expensive cost.

- Appropriate Field of View (FoV) and camera resolution which allow object identification in details. Wide-angle cameras are desirable in wide area surveillance applications. Optics and reflectors are used in front of the camera sensor to widen the FoV, but resolution of the camera sensor is normally fixed. Perspective effect through the image projection may result in insufficient amount of pixels to represent an object on the scene. Therefore, object at a certain distance for the camera cannot be accurately identified.

### 2.2.2 Lens distortion

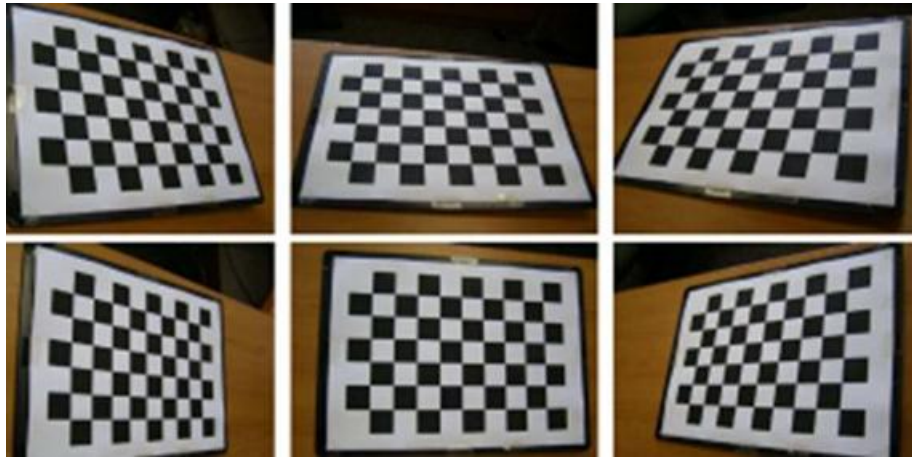
Lens distortion has been one of the major problems in video surveillance especially in the subject identification. The most frequently found distortion is in the radial direction which is called radial distortion. This affects all wide-angle cameras which use three different types of lens. Therefore, three major types of distortion are Barrel, Pincushion and Fisheye distortions as shown in Figure 2.1 [6]



**Figure 2.1** (a) Barrel, (b) Pincushion, and (c) Fisheye Distortion

Radial distortion can be corrected using a camera calibration tool which will reconstruct the distorted image into a flat image. The calibration's procedure may

involve using the camera to take a few pictures of a checker board pattern. The checker board has a certain physical dimension that can be further extracted to define the distortion parameters. Once the parameters are known, the inverted distortion can be applied to the distort image to obtain the flat image as show in Figure 2.2



**Figure 2.2** Checker board pattern used for camera calibration

There are a variety of tools for digital image forensics which are a combination of analytical software and image processing. The computation process must have details explanation of what procedures have been applied to the image. The following tools has been widely used for the purpose of digital image forensics nowadays,

1. MATLAB is a scientific software that used in various fields of research. It stated of as a tool to help solving vector and matrix problems. In recent years, more analytical features are added as toolboxes that allow MATLAB to have a rich set of libraries for various computational research. Image processing toolbox has been developed with many features that allow researcher to exploit various aspect of an image. For example, image authenticity can be computed by using MATLAB script with the image processing toolbox [7].

2. Amped is an image processing software for digital image forensic and investigation. It contains various features in image forensics both for still and motion

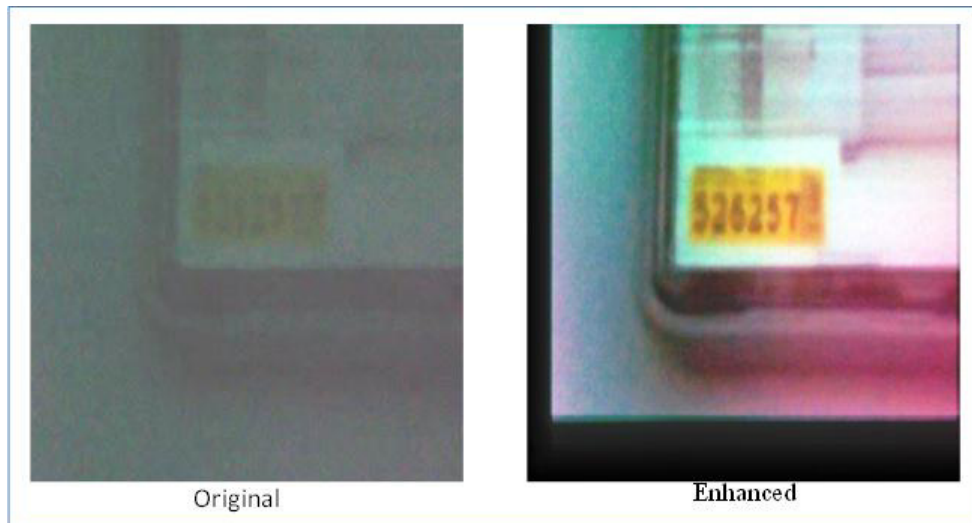
images. The computation is designed to be high efficiency and high performance. It has a workflow that is comprehensive and understandable. [8].

The features include image de-blur and video stabilization that allow that user to see the output interactively. Therefore, the user can perform the operation in trial-and-error mode on the image until it reaches the clarity sufficient for submitting as an evidence.

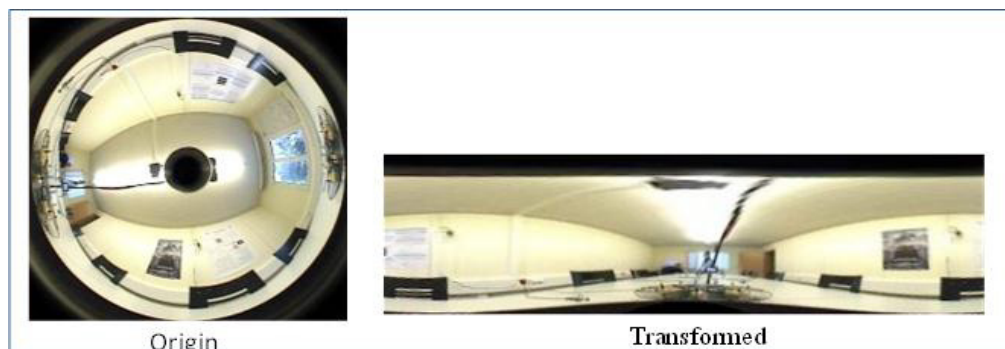
Examples of Amped results are shown in Figure 2.3-2.5 which include measuring height, brightness and contrast, and geometrical transformation.



**Figure 2.3** Measure heights of objects from an image

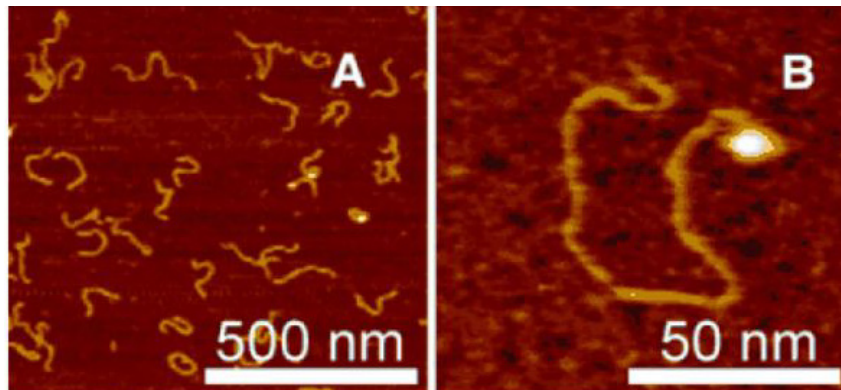


**Figure 2.4** Brightness and contrast enhancement



**Figure 2.5** Geometrical transformation of an image

3. ImageJ is an image processing program developed by Wayne Rasband at the National Institute of Health (NIH), USA. This program are written in JAVA for image analytic such as counting blood cells, the length of DNA as shows Figure. 2.6, computing area of coverage of objects, etc. It is an open source platform for image processing applications. Therefore, it is also a potential tools for digital image forensics. [9]



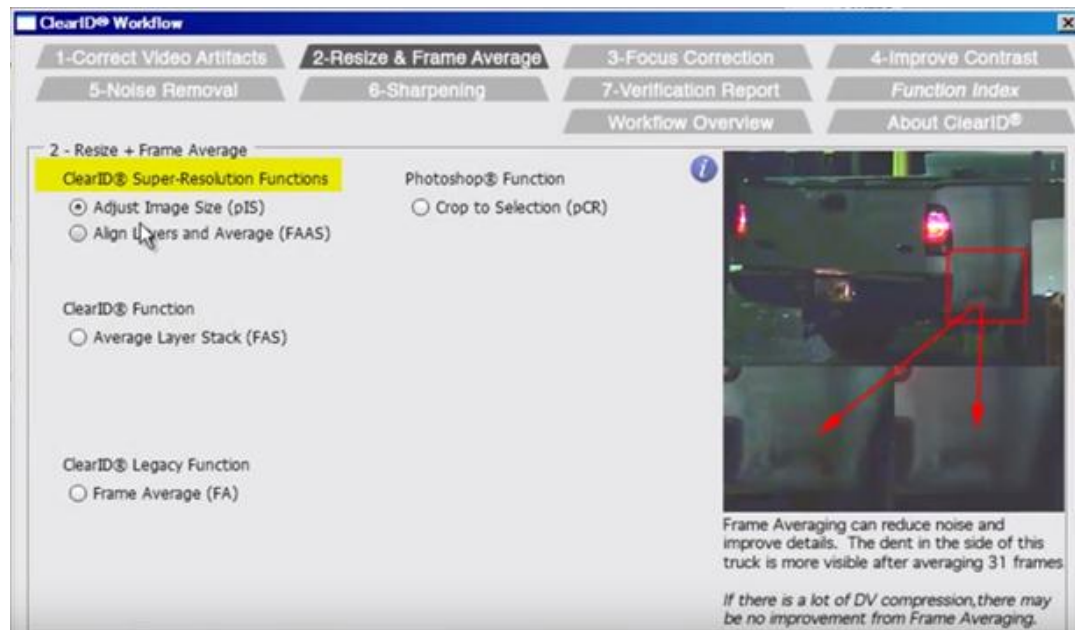
**Figure 2.6** Preview the length of the DNA in ImageJ

4. SmartDeblur™ is a software for image restoration that improve the image quality by using mathematical model. Blurry image can be a result of off-focus photography and motion. If the mathematical model of the blurry effect can be estimated, the inversion of such effect can be performed to restore the corrupted image to its original [10]. The example results of motion deblur is shown in Figure 2.7.



**Figure 2.7** Corrupted image by motion blur is on the left and the restore image, on the right, is the result from motion deblur

5. Photoshop Plugins [11] can also be used in digital forensic purposes. Normally, it is an image editing software that allow the user to manipulate the image data. In recent year, the plugin that has the forensic capability has been released such as Forensic Image Clarification. The example features are shown in Figure 2.8.



**Figure 2.8** Example frame averaging can reduce noise and improve detail. The dent in the side of this truck is more visible after averaging 31 frames

In this research, we focus on the mathematical transformation that restores the visual proportion of the captured images. Since the 360-degree images are based on a spherical coordination system where the location of the pixel are not linearly proportion to the actual object. In spherical coordinate, the pitch and azimuth angles are used as reference. The camera can capture a hemisphere image that provides a large area of coverage. The main disadvantage is that the image produce by the camera has a highly distorted geometry that is not suitable for measuring. Therefore, it requires a new algorithm to reconstruct the image to display object in a correctly proportional size. Consequently, the reconstructed image can be used for subject identification.

## **CHAPTER III**

### **RESEARCH METHODOLOGY**

This research aims to develop a new algorithm for measuring size of objects in the image produced by a 360-degree camera. Our objective is to develop a mathematical model of the optical flow of the 360-degree camera. The second objective is to transform the original 360-degree image to a geometrically corrected image that are suitable for measuring. The last objective is to provide the assessment of accuracy of the model and the image transformation algorithm.

Two types of 360-degree camera are used in our research experiment. One is the ceiling model that claims to capture 360-degree view, but, in fact, it can only capture half a spherical viewing angle underneath the ceiling. The second model is the true 360-degree camera that can capture the entire spherical viewing angle of the environment. In our experiment, the ceiling model is used as a preliminary study for the mathematical modeling of all the optical path through the imaging sensor of the camera.

#### **3.1 Preliminary study**

In the ceiling model experiment, the hardware consists of,

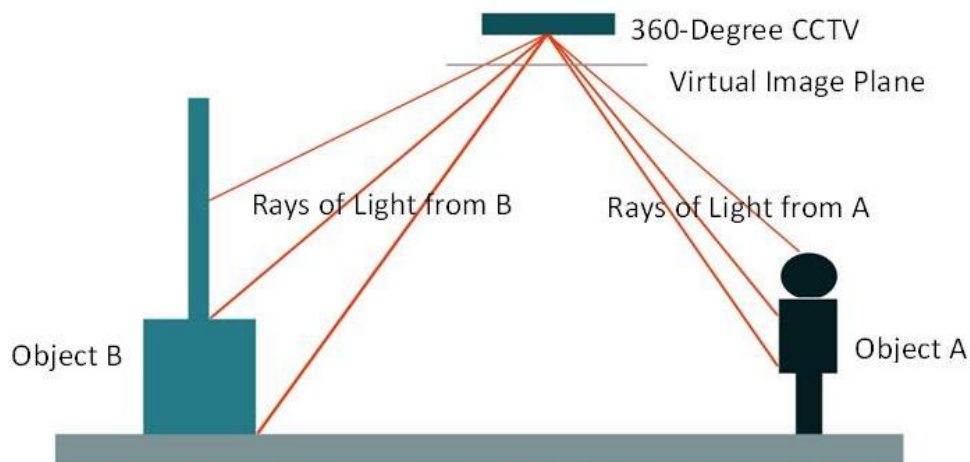
1. A 360-degree camera mounted on the ceiling at a specific height from the ground
2. A personal computer used for digital image capturing and image processing. An algorithm to restore the correct proportion of the object is developed based on the mathematical modeling of the optical flow.
3. A test environment which is an indoor area which has some detail measurement of specific location.
4. Some objects that are used as phantoms. These phantoms are the objects with some measurements are known.

5. A measuring device such as a ruler or a measuring tape.

The software is written in MATLAB which implements the mathematical model based on the optical flow of the ceiling model. The mathematical model of the optical flow of a 360-degree is first developed based on a pinhole camera model. The camera will have light projections from all directions that are less than 90 degrees perpendicular to the surface normal of the image sensor as shown in Figure 3.1.

Our approach is to transform the light projection at the virtual image plane onto the new plane. This new plane is created virtually with the assumption that it is located at the center of the object and perpendicular to the ground. The projection of the light created a pixel formation that is a flat estimate of the distorted 360-degree image.

After the new projection algorithm developed, the experiment begins with installation of the 360-degree camera as shown in Figure 3.1. The camera is connected to a personal computer that is capable to image acquisition and some image processing software for computation of the projection algorithm. Some objects of known size are placed on the scene so that verification of the measurement can be assessed.



**Figure 3.1** The 360-degree model based on pinhole camera model

As shown in Figure 3.1, the projection of the rays of light on the virtual image plane is related to the angle perceivable by the camera. Therefore, another virtual plane can be created right on the object. The projection of the rays of light back

to this plane will create an image that is measurable in pixel. In this preliminary experiment, we allow the user to select the object where the virtual planes that are perpendicular with the ground and the surface normal of the plane also perpendicular to the circumference of the camera. Hence, many objects on the scene can be measured in pixels. If the height of the camera is known, each pixel can be translated into a measurement unit such as meter or millimeter.

The experiment requires at least 30 repetitions of different setups. After each measurement taken, the errors are recorded and the average and standard deviation of the error will be calculated. The low average error shows that the precision of the measurement through the new projection is good while the low standard deviation of error shows that the accuracy or repeatability of the algorithm is good.

**Table 3.1** The error of measurement of some known object in an image

<b>Fixed size objects</b>	<b>Actual length (cm.)</b>	<b>The average length measured from the image. (cm.)</b>	<b>Error</b>
The height of the counter	105	103.3	2%
The width of the counter	110	115.7	5%
The height of the elevator	220	215.0	2%
The width of the elevator	120	118.3	1%

This experiments indicated that the mathematical modeling of the optical flow can restore the object proportion that are distorted from the camera field of view. The maximum error is about 5% without camera calibration.

### **3.2 Methodology**

In this research, we aim to apply the projection technique from our preliminary study to overcome the distortion in the true 360-degree camera. A 360-degree camera such as the one shown on Figure 3.2 which used multiple cameras to

cover all 360-degree field of view. We proposed the geometric transformation from a spherical coordinate to a cylindrical coordinate to reduce the distortion of object at a very low and very high angle. If an object appears at such location its pixels are highly compressed. Therefore, detail information cannot be captured and the object appears to be highly distorted. Measurement of the object dimension become very difficult.



**Figure 3.2** An example of a true 360-degree camera which uses 2 ultra-wide angle cameras to cover the entire 360-degree field of view

The next step is to project the rays of light from the cylindrical coordinate to a flat surface so that the object will appear in a normal proportion which is suitable for measurement. In this research, we develop a mathematical modeling based on these transformations. The spherical to cylindrical transformation and the cylindrical to flat transformation are detailed in the next section. The back projection technique which is the main contribution of our research that help to correct the proportion of the object based on the spherical projection.

### 3.3 Materials

Additional materials that are used in this research are explained in this section. The spherical coordination system is used to define the pixel location on the

360-degree image. The transformation to cylindrical and flat surface is the attempt to undo the distortion from the imaging system. Hence, the measurement can be performed with accuracy.

### 3.3.1 Spherical coordinate system

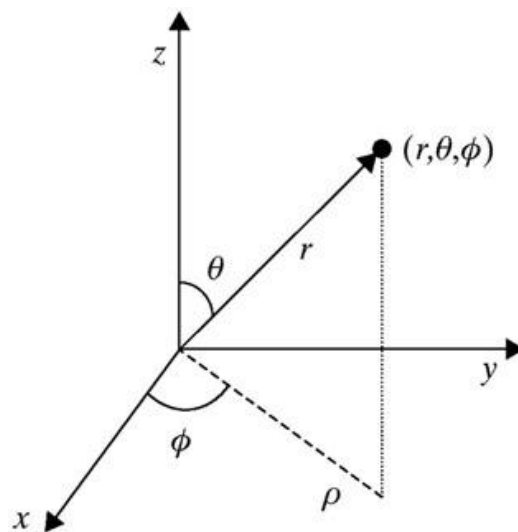
Spherical coordinate system is defined by  $(r, \theta, \phi)$  where  $r$  is the absolute distance from the origin,  $\theta$  is the pitch angle from the  $z$ -axis and  $\phi$  is the azimuth angle in the  $x$ - $y$  plane as shown in Figure 3.2. The spherical coordinate system is related to the Cartesian coordinate system through the following equations:

$$r = \sqrt{x^2 + y^2 + z^2}, \quad (3.1)$$

$$\theta = \tan^{-1} \left[ \frac{\sqrt{x^2 + y^2}}{z} \right], \quad (3.2)$$

$$\phi = \tan^{-1} \left( \frac{y}{x} \right). \quad (3.3)$$

The  $(x, y, z)$  in equation 3.1-3.3 are the location inside the Cartesian coordinate. There is no loss in the conversion between these coordination systems assuming that no truncation and quantization are used in the calculation.

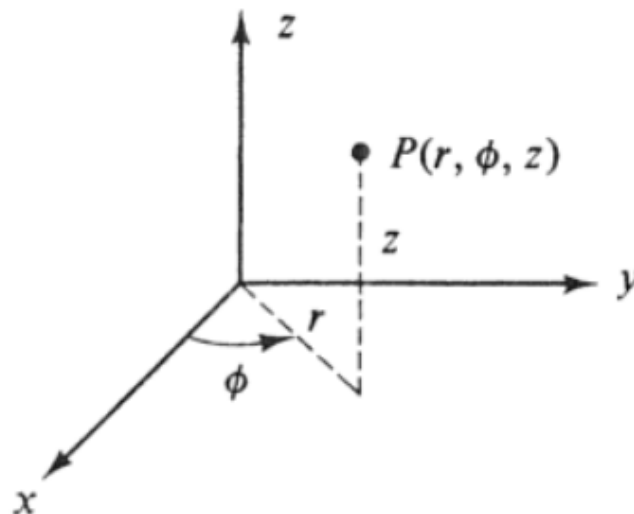


**Figure 3.3** A spherical coordinate system

In 360-degree camera, pixel information is formed according to its pith angle and azimuth on the spherical coordinate. Therefore, the pixel location can be mapped from location  $(x, y)$  on the image to the  $(\phi, \theta)$  of the spherical coordinate system. The  $(\phi, \theta)$  represents the direction of a ray of light that form a pixel at location  $(x, y)$  on the image.

### 3.3.2 Cylindrical coordinate system

Position in cylindrical coordinate can be determined by  $(r, \phi, z)$  where  $r$  is the distance from origin,  $\phi$  is the azimuth angle, and  $z$  is the distance from the  $x$ - $y$  plane as shown in Figure 3.3.



**Figure 3.4** A cylindrical coordinate system of  $(r, \phi, z)$

From the Cartesian coordinate system, the following formulas are used to transform the coordinate into cylindrical coordinate system. This conversion is conserved which implies that there is no loss in the conversion.

$$r = \sqrt{x^2 + y^2}, \quad (3.4)$$

$$\varphi = \begin{cases} 0, & x = y = 0 \\ \sin^{-1}\left(\frac{y}{r}\right), & x = 0 \\ \tan^{-1}\left(\frac{y}{x}\right), & x > 0 \\ -\sin^{-1}\left(\frac{y}{r}\right) + \pi, & x < 0 \end{cases} \quad (3.5)$$

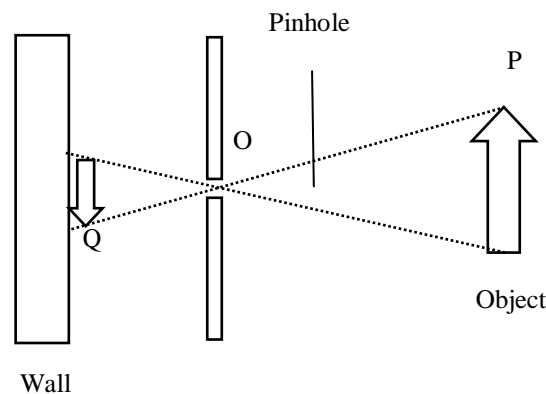
Where the  $(x, y, z)$  coordinate represent a location P in the Cartesian coordinate system.

The mapping from a spherical coordinate system to a cylindrical coordinate system is the key to compute the back projection of the rays of light which will undo the distortion of the 360-degree image. The pixel information is formed on the imaging sensor based on the ray of incident light. If the light is projected back in the opposite direction to the surface formed by a cylinder. The distortion of the objects at the low and high angle can be eliminated. In the next section, backward projection technique will be explained.

### 3.3.3 Back-projection technique

The most common model of imaging device is a pin-hole camera. The concept of the pin-hole camera relies on the physic of light. As shown in Figure 3.4, the light from the object at location P passes to a hole at location O and create a projection on the wall at location Q. The image of the object will appear up-side-down on the wall. If the wall is replaced by a sensor that convert light into electrical signals, a digital image can be formed.

To form a 360-degree image, we can imagine that entire imaging system is spinning above the wall's vertical axis rapidly. Therefore, light from all direction can enter the sensor as a result the 360-degree image can be made. This scenario provides the basis for the camera model that allow us to capture light from all directions. In reality, there is no need to spin the camera since the imaging sensors are affordable. Multiple camera can be used to capture the entire 360-degree angle at once which is more reliable than the mechanical rotation. Although the implementation is different, the spinning camera model can still be used as a reference model in the computation. It provides the linkage between the pixel rendition and the direction of the ray of light.



**Figure 3.5** Pin-hole camera model

When the image is formed on the imaging sensor. Each pixel of the image is the result of the incident ray that activates the response of imaging sensor. Therefore, this provides the trace for the backward projection technique. Every pixel position provides the direction to trace back to the object where the light initiated. If the light is projected back to such direction hits a new surface, it can form a new pixel. In this research, the 360-degree image is using a spherical coordinate system. A transformation from the spherical coordinate to cylindrical coordinate is based on the idea that the backward projection from the sphere will hit the new wall which is a cylindrical shape with the same radius as the sphere. Hence, the distortion in the vertical axis is eliminated.

### 3.4 The Experiment

In the main experiment, one scenario has been designed. The scenario will include an object of interest and its environment. The object is a manikin which has a known height. The 360-degree images are taken in various distances and angles. There is a reference object on the scene which has a fixed size, in this experiment, the camera tripod is used because the distance between each leg of the tripod is constant throughout the image capturing procedure.

The experiments procedures start with

- Set up the scenario as mentioned earlier.

- Position the camera from the depth distance of 30, 60, 90, and 120 centimeters. For each depth, move the camera sideway to the left-right position by -60, -30, 0, 30, and 60 centimeters. For each left-right position, vary the height of the camera from 120, 150, and 180 centimeters. Therefore, the total amount of images in this experiment is equal to 60 images.

- Use the software developed using MATLAB to undo the distortion. The source code of the programs are provided in the Appendix. The program is using the backward project technique to create an undistorted image from the 360-degree image.

- The user is required to use a mouse to click at the position of the object and some reference points, and input the tripod length. The program gives a proportional image of the object, the camera height, the height of the object as the outputs.

- The error is measured against the actual height of the object which is 180 centimeters. The average error is calculated.

- The proportion image is reviewed by the experts who have experiences with suspect identification. A questionnaire is developed to validate the outcome of the program.

In the next chapter, the experiment results will be provided. The average error will also be presented.

## CHAPTER IV

### EXPERIMENTS AND RESULTS

In this chapter, the results from the experiment is provided. The experiment is conducted using a developed program written in MATLAB. We start this chapter by displaying some output images from the program and compare with the original (distorted) 360-degree image. Then, the accuracy assessment of the measurement is shown in a table and the average errors for each case is shown. In section 4.1, we present experiment results and compare results of three algorithms in the section 4.2. Finally, we explain about limitation of this research.

#### 4.1 Image transformation Outputs

A sample image from a 360-degree image is shown in Figure 4.1. The image was captured through a 360-degree camera, the Ricoh Theta S, in JPEG format. As mentioned in the previous chapter, the low and high angle (upper and lower part of the image) areas are more compressed. Therefore, the object, especially the feet, looks distorted and difficult to make any measure.



**Figure 4.1** A 360-degree image of the scenario from the experiment

The developed program transforms the original image in Figure 4.1 and produces the output as shown in Figure 4.2. This is the result from backward projection from spherical coordinate to cylindrical coordinate. The object appears to be in better proportion compared to the original image in Figure 4.1. This projection may not be perfect since it makes some assumption through the following mathematical model.

$$H_c = \frac{d}{\tan \theta_0}, \quad (4.1)$$

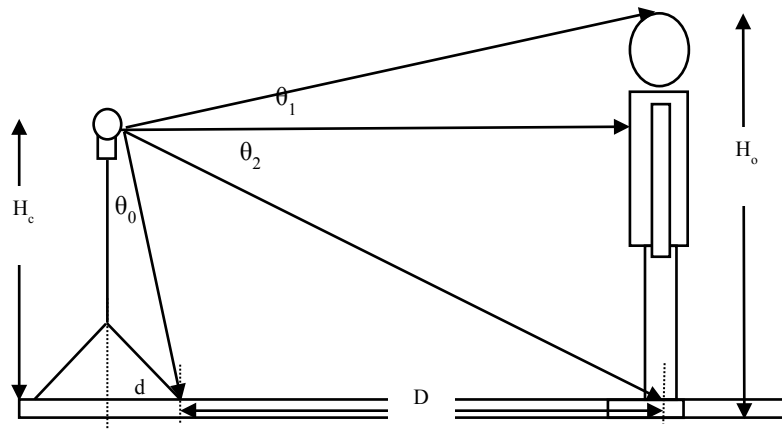
$$D = \frac{H_c}{\tan \theta_2} - d, \quad (4.2)$$

$$H_o = (D + d) \cdot \tan \theta_1 + H_c. \quad (4.3)$$

where  $H_c$  is the camera height,  $D$  is the distance from the leg of the tripod to the leg of the object,  $H_o$  is the estimated height of the object. The rest of the variables are the angles that can be extracted with the help from the user's mouse click. The mathematical model is developed from the scene modelling shown in Figure 4.3.



**Figure 4.2** The backward projection outputs as the result from spherical coordinate to cylindrical coordinate mapping



**Figure 4.3** The scene modelling of the experiment

### 4.2 Measuring height

The position and height of the 360-degree camera are varied from the depth of 30, 60, 90 and 120 centimeters and the left-right distance of -60, -30, 0, 30, and 60 centimeters, and the height of 120, 150 and 180 centimeters. In total, there are 60 images in the experiment. The actual height of the object is exactly 180 centimeters. The estimated heights are shown in Table 4.1

**Table 4.1** Height of object measured by the developed program

Camera Height (cm)	Left-Right Distance (cm)	Depth Distance (cm)			
		30	60	90	120
120	-30	175	177	178	193
	-60	180	175	182	185
	0	191	178	181	184
	30	192	177	183	175
	60	183	173	183	190
150	-30	190	174	183	184
	-60	190	177	182	178
	0	191	178	184	179
	30	189	175	184	182
	60	192	180	183	183

**Table 4.1** Height of object measured by the developed program (Continue)

Camera Height (cm)	Left-Right Distance (cm)	Depth Distance (cm)			
		30	60	90	120
180	-30	190	179	182	187
	-60	189	181	183	184
	0	192	188	184	187
	30	189	178	184	189
	60	189	177	183	185
Max		192	188	184	193
Min		175	173	178	175
Average		188.13	177.80	182.60	184.33
% Error		4.52%	1.22%	1.44%	2.41%

The bottom of Table 4.1 show some statistics from the estimated measurement from the image. The error are calculated and shown in percentage through the following equation,

$$Error = \frac{|estimated - actual|}{actual} \times 100, \quad (4.4)$$

where the estimated is the measure taken using the program and the actual is the actual height of the manikin which is 180 centimeters.

The results show that the average error is within 5% of the actual measurement which is useful for many application. It may not be sufficient to identify a suspect based on height alone, but this can be used in filtering the suspects in the database. Therefore, screening has become a very useful tool to reduce and focus on a certain group of suspects.

In the next chapter, some discussions will be provided in the areas related to the factors that are contributed to the error and how to improve the accuracy. Some of the topics are a potential trailer to this research which will be suggested in the last chapter.

### **4.3 Face Identification**

For this experiment, the output image are cropped for the facial area and compared with a picture taken from a normal camera in a similar configuration which is also known as a mug shot. The comparison is performed by an experience personnel in the field of facial identification. The questionnaire is aims to validate whether the facial identification can be successfully performed on the image and what are the obstacles and factors that inhibit the facial identification process.

The feedbacks that we receive from the evaluation are,

- The image is somewhat blurry

In the next chapter, some discussions will be provided in the areas related to the factors that are contributed to the error and how to improve the accuracy. Some of the topics are a potential trailer to this research which will be suggested in the last chapter.

## **CHAPTER V**

### **CONCLUSIONS**

In this chapter, discussion of what are the main factors that contribute to the accuracy of the measurement in 360-degree image is presented. The second topic in the discussion is how to improve the computation for a better accuracy and easy of usage.

#### **5.1 Accuracy Factors**

The factors that impact the accuracy of the measurement of the 360-degree image can be divided into two types. One is the error contributed by the modeling and computation. The other is from the human user. Both can contribute to the error in the measurement which can be discussed in details in the following sections.

##### **5.1.1 Modeling and Computational errors**

In practice, when a 360-degree image is given, the first step is to develop the mathematic model of the scene and determine the object to be measured and the procedure to acquire such measurement. Drafting and sketching are the basis to a good modeling. The more detail elaboration on the model will result in highly accuracy in the calculation. In many cases, there are too much unknown, hence, assumptions and estimation are made. Therefore, the model is under some kinds of approximation as the result. If this happens, it is normally can be tuned to an acceptable errors. Some small errors can also happen from truncation and quantization of digital numbers.

Another factor is the image resampling technique. When the backward projection is performed, it computes the position where the ray will be projected and then find the four adjacent pixel that are the closest neighbor in order to compute the bilinear approximation of the intensities. This will sometimes result in a blurry image. The improvement can be easily made by changing from bilinear approximation to bi-

cubic approximation. In general, this will preserve the sharpness of the image better than the bilinear counterpart.

There could be others factors which may contribute to higher errors. Mistakes and bugs in programs may be present, but there is no need to have discussion. It is the quality issue of the production of the program which needs software engineering to be deployed.

### **5.1.2 Human errors**

The program requires that the user must use a mouse to click on a certain path of the object such as the head, the feet, and etc. which will be a reference points for the subsequent calculation. If the screen does not provide sufficient resolution for accurately click on the right location, the information that gets into the equation will not be correct. Therefore, the output cannot be correct which implies high error. This problem can be overcome by using sufficiently high resolution to do this task. Improvement on the point device may also be a good idea. Those who use a laptop may use a touchpad as the primary pointing device. The nature of touchpad do not provide high accuracy and the ease of controlling the position when compared to a professional grade optical mouse.

Aside from improvement on the human-machine interface, the user must develop the skills to click at the proper location as the reference. For example, if a human subject appears on the scene and we need to give the system two points: one at the feet and the other at the head. What happen if the two feet are at different distances from the camera? Where should the user click to provide the reference for the measure? This is a kind of skills that the user must possess to accurately measure the object on the image.

## **5.2 Potential Improvements**

There are many aspects to improve the measuring process. The feedbacks from the expert users already gave some ideas about what to improve such as sharpness of the picture, and resolution of the image. In the extreme aspect, the system consists of one camera which is insufficient to determine the size of the object without

providing a reference (known size) object. The detail will be discussed in the next sections.

### **5.2.1 Image Improvements**

For the sharper image, the backward projection technique employs the bilinear approximation to perform image resampling which makes the image blurry. To fix the problem, bi-cubic approximation can be used for the same purposes without incurring blurry effect.

### **5.2.2 Automatic 3D 360-degree camera**

By deploying more than one 360-degree cameras, it is possible to render the entire 360-degree scene automatically. All perceivable objects and angles can be three dimensionally reconstructed; hence, there is no need for a reference object. Additional researches are needed to make such a system happen and function accurately.

## **5.3 Conclusion**

In this chapter, various aspects of discussion are covered. More researches are needed to develop a system such as in 5.2.2

## **CHAPTER VI**

### **CONCLUSION AND FUTURE WORK**

#### **6.1 Conclusion**

In this research, a photogrammetry program is developed for measurement of object from a 360-degree image. The program relies on a mathematic model of the scene where the image was taken. This requires some knowledges and assumptions of the composition of the scene. To validate the program, an experiment is conducted based on a simulated scenario with known-size object as details in Chapter 3 and Chapter 4. Some variations in the distances and angles are introduced into the experiment. The error analysis shows that the average error is within 5% which is suitable for screening in the suspect identification procedure. Some discussions of the outcomes is presented in Chapter 5.

An additional validation is for the qualitative aspect of the 360-image transformation. In general, the 360-degree image when displays on a rectangular screen will appear distorted. As a result, the facial features of the human subjects will also be distorted. One of the outputs of the developed program is the flat image which is the transformation from spherical to flat surface's projection. This flat images are reviewed by users who have experiences with facial identification. The flat images from the program receive a satisfaction level from the review.

This research will allow the use of 360-degree images to be used as digital evidence effectively. Measurement can be made for screen purposes and the flat image can be used for facial identification. From this research, we notice that additional works beyond the proposed scope is necessary for the system to be robust and accurate. Some potential works will be detailed in the next section.

## **6.2 Future Works**

The current work is consider the first version of the measurement with 360-degree image. This version requires some knowledge from the scene to establish a mathematical model and some reference points to provide the linkage to the physical world. The mathematical modelling is a manual procedure which is a non-trivial and time consuming task. It would be highly desirable if the system can estimate the model automatically.

In the development of the next version, an automatic model of the scene will require some statistics of what to measure and what environment is there. For example, measure the height of a man standing straight on the ground, measure the distance of the man from a vertical wall, etc. If all the scenario can be studied, the automatic model can also be accomplished.

## **6.3 Potential Improvements**

There are many aspects to improve the measuring process. The feedbacks from the expert users already gave some ideas about what to improve such as sharpness of the picture, and resolution of the image. In the extreme aspect, the system consists of one camera which is insufficient to determine the size of the object without providing a reference (known size) object. The detail will be discussed in the next sections.

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## **APPENDICES**

## **APPENDIX A**

### **SOFTWARE**

The software used in this research can be executed inside MATLAB environment. Several MATLAB functions are developed as the source code is listed in Appendix B. In this section, the software usage is presented.

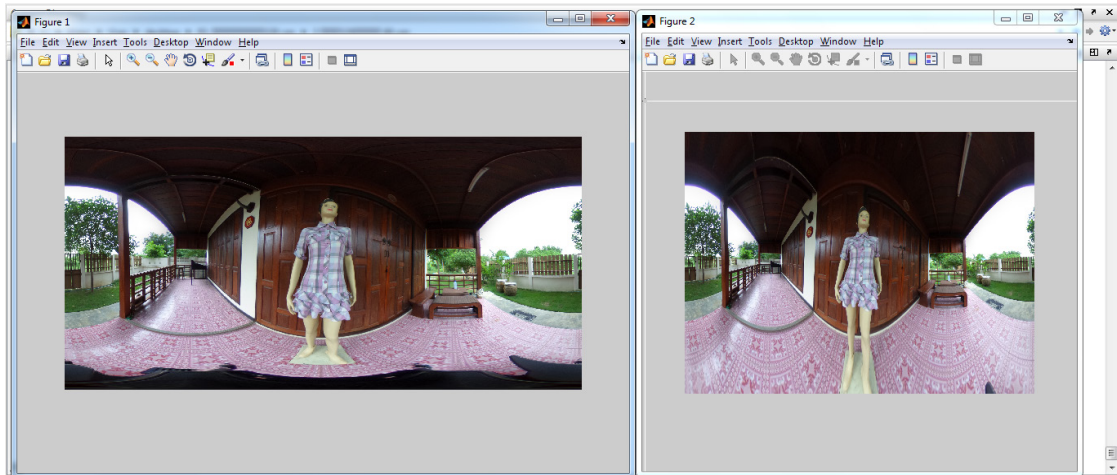
#### **Software Installation**

For simplicity, all functions and pictures file are kept in the same folder. The user must change the current folder inside MATLAB to the program folder before calling the functions.

#### **Software Usage**

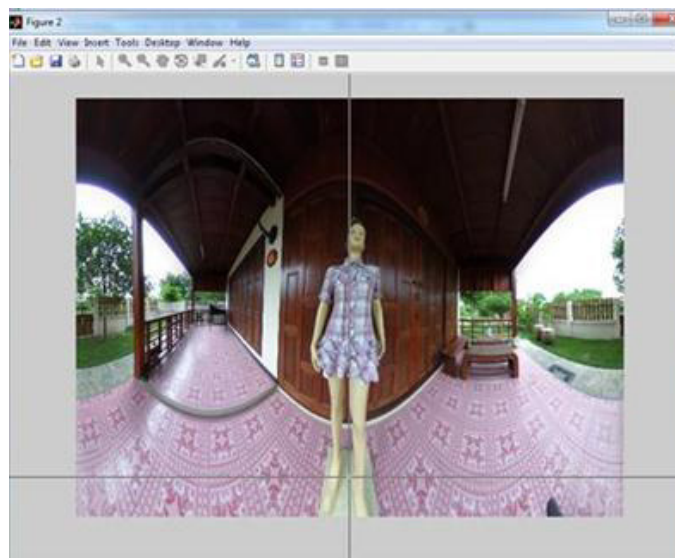
The primary function is `imsp2flat` which the usage is as follow, `image out = imsp2flat(filename, scale, width, height)`, where the `image_out` is the output image, the `filename` is the name of the input image file, the `scale` is the scaling factor, the `width` and `height` are the width and height of the output image in pixel. The scaling factor less than 1.0 implies the image size will be smaller than its original size. If the number is greater than 1.0 the image is magnified.

For example, if the user type the following command, `img = imsp2flat('picture1.jpg', 0.5, 1024, 2048)`, two windows will popped up as shown in Figure A.1.



**Figure A.1** The screen shot of the program.

In Figure A.1, the windows on the left shows the input image which is a 360-degree image. The windows on the right shows the output image after the spherical to cylindrical coordinate transformation. The user must use a pointing device to choose the horizontal location of the object, so that the cylindrical to flat coordinate transformation can be performed as shown in Figure A.2. The output image, shown in Figure A.3, is 1024 pixels in width and 2048 pixels in height.

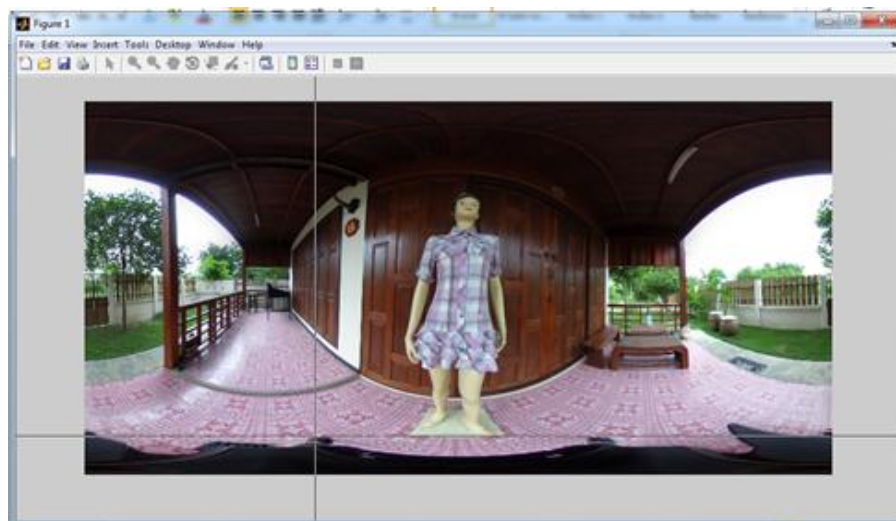


**Figure A.2** The user select the horizontal location where the object is located.

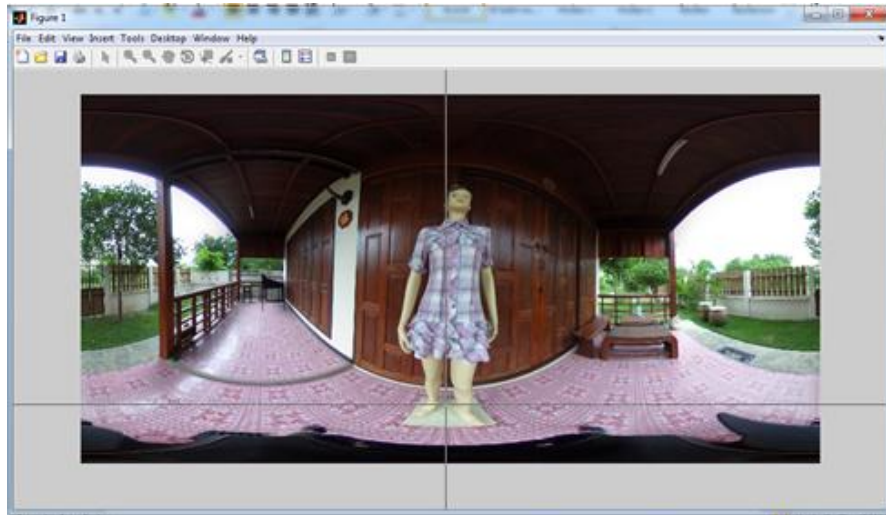


**Figure A.3** The output image

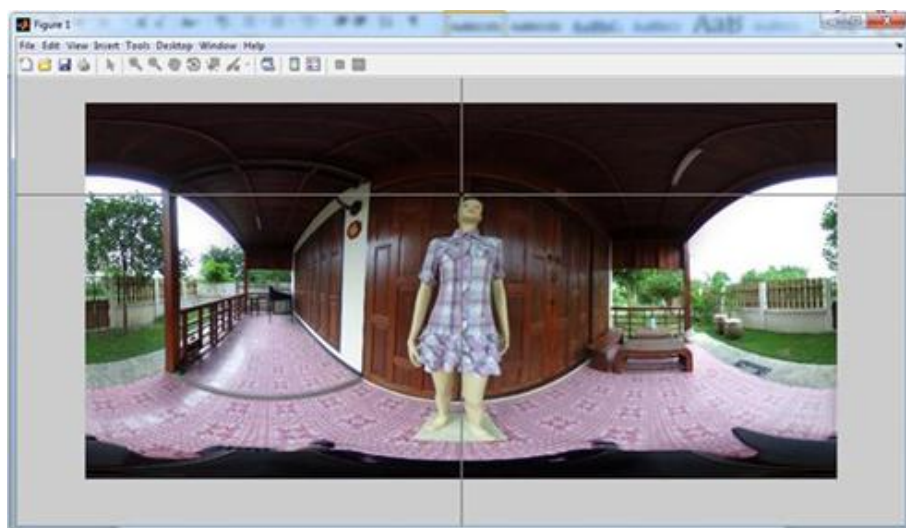
In the next step, the user uses the pointing device to choose the estimate location of the tips of the tripod leg, the ground, and the head to predict the height of the object as shown in Figure A.4, A.5, and A.6 respectively. Once all the three points are determined, the user must supply the distance between the tripod legs, so the height of the object can be estimated as shown in Figure A.7.



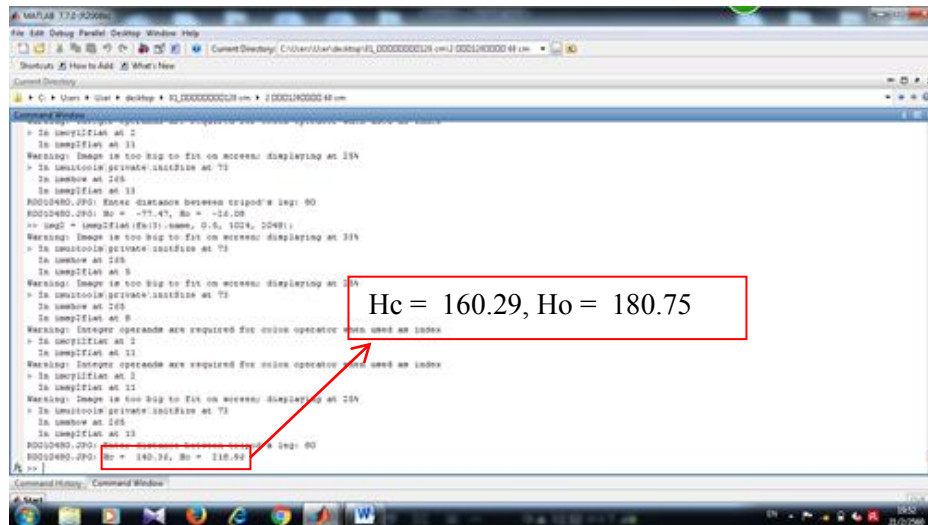
**Figure A.4** The user locates the tripod's legs.



**Figure A.5** The user selects the ground reference.



**Figure A.6** The user select the top of the head to estimate the height.



**Figure A.7** The height is estimated by the software.

## APPENDIX B

The source code of the program are as follows,

```

function img2 = imsp2flat (fname, scale, W, H)
a = imread(fname);
a = imresize(a, scale);
figure(1);
imshow(a);
b = imcylmap(a, H);
figure(2);
imshow(b);
figure(2);
[x, y] = ginput(1);
img2 = imcyl2flat(b, x, W);
figure(3);
imshow(img2);
% extract height
figure(1);
[x, y] = ginput(3);
[M, N, dummy] = size(a);
M2 = M/2;
N2 = N/2;
theta0 = pi/2 - pi*(y(1) - M2)/M;
theta1 = -pi*(y(3) - M2)/M;
theta2 = pi*(y(2) - M2)/M;
fprintf('%s: ', fname);
r = input('Enter distance between tripod''s leg: ');
d = r/(2*cos(30*pi/180));
%d = r;
Hc = d/tan(theta0);
Ho = Hc*(tan(theta1)/tan(theta2) + 1);
fprintf('%s: Hc = %7.2f, Ho = %7.2f\n', fname, Hc, Ho);
function img2 = imcylmap(img1, height)

```

```
[m, n, depth] = size(img1);
mx = zeros(height, n);
my = mx;
for i = 1:height,
    mx(i, :) = 1:n;
    my(i, :) = m/2 - atan2(height/2 - i, m/pi)*m/pi;
end
if depth == 1,
    img2 = imsamp1(mx, my, img1);
else
    if depth == 3,
        img2 = imsamp3(mx, my, img1);
    end
end

function img2 = imcyl2flat(img1, ang, width)
[m, n, depth] = size(img1);
d = ang - n/2;
if d < 0,
    img1 = [img1(:, n+d+1:n, :), img1(:, 1:n+d, :)];
else
    if d > 0,
        img1 = [img1(:, d+1:n, :), img1(:, 1:d, :)];
    end
end
end
w2 = width/2;
r = n/2/pi;
mx = zeros(m, width);
my = mx;
for i = 1:width,
    mx(:, i) = atan2(i - w2, r)*n/(2*pi) + n/2;
    my(:, i) = 1:m;
end
if depth == 1,
    img2 = imsamp1(mx, my, img1);
else
    if depth == 3,
        img2 = imsamp3(mx, my, img1);
    end
end
```

```
end
function img2 = imsamp1(mx, my, img1)
[m, n, depth] = size(img1);
mx = min(n, max(1, mx));
my = min(m, max(1, my));
mx0 = floor(mx);
mx1 = ceil(mx);
my0 = floor(my);
my1 = ceil(my);
if depth > 1,
    img2 = [];
    return
end
img00 = zeros(size(mx));
img00(:) = img1((mx0(:)-1)*m+my0(:));

img01(:) = img1((mx0(:)-1)*m+my1(:));
img10 = zeros(size(mx));
img10(:) = img1((mx1(:)-1)*m+my0(:));
img11 = zeros(size(mx));
img11(:) = img1((mx1(:)-1)*m+my1(:));
dx = mx - mx0;
dy = my - my0;
img0x = img00.*(1-dy) + img01.*dy;
img1x = img10.*(1-dy) + img11.*dy;
img2 = uint8(img0x.*(1-dx) + img1x.*dx);

function img2 = imsamp3(mx, my, img)
[m, n, depth] = size(img);
img2 = [];
if depth == 3,
    r = imsamp1(mx, my, img(:, :, 1));
    g = imsamp1(mx, my, img(:, :, 2));
    b = imsamp1(mx, my, img(:, :, 3));
    img2 = cat(3, r, g, b);
end
```

## **BIOGRAPHY**

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