OPTICAL ALIGNMENT OF NON-IMAGING DISH CONCENTRATOR USING TARGET REFLECTION TECHNIQUE

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor (Hons.) of Electrical and Electronic Engineering

Lee Kong Chian Faculty of Engineering and Science
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September 2016

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : ____________________________

Name : ____________________________

ID No. : ____________________________

Date : ____________________________

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"OPTICAL ALIGNMENT OF NON-IMAGING DISH CONCENTRATOR USING TARGET REFLECTION TECHNIQUE"** was prepared by **TEO JUN YI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : _______________________

Supervisor : Mr. Wong Chee Woon

Date : _______________________

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ABSTRACT

Throughout the development history of concentrator photovoltaic (CPV) systems, many designs of concentrators have been introduced. These concentrators consist of numerous facet mirrors mounted on the structure to reflect the sunlight onto a target, which is made up of modules of high efficiency solar cells. The high efficiency multi-junction solar cells are able to achieve as high as 46% conversion efficiency under adequately high solar irradiance. However, to attain the maximum solar concentration ratio, all the reflected images from facet mirrors must be precisely aligned to reflect onto the target, and images from all facet mirrors are super positioned. Over the years, one of the common method of alignment is by using mechanical alignment, to manually tilt the facet mirror and reflect the sunlight image onto the target. The main drawback of this method is that, by matching the reflected image onto the target using human naked eye, the precision can be very low as human mind cannot judge the location of the target precisely, thus causing mismatch on the solar irradiance and dropping of conversion efficiency due to losing of partial irradiance. Therefore, to improve the alignment precision of facet mirrors and also the efficiency of the solar concentrator, a novel approach of alignment is introduced in this project, which is using optical alignment method and target reflection technique. This method uses a high resolution camera to capture the image of mirror, and then it is processed using the image processing algorithm and the centre point of each facet mirror is calculated. The reflected image of the centre point of target is then aligned with the centre point of the mirror. This method of alignment requires proper levelling of the target to provide an accurate reference to all facet mirrors for tilting, and also levelling of camera optical axis is required, to provide accurate

tilting angle with reference to target board. The leveller used has an accuracy of up to 0.2 °. The analysis of error caused by accuracy has been done and discussed.

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LIST OF SYMBOLS / ABBREVIATIONS

X	pixel value in x-direction
Y	pixel value in y-direction

mrad	milli- radian
NIDC	Non-Imaging Dish Concentrator
TOP	Theoretical Overlay Photographic
HCE	Heat Collection Element
IDE	Integrated Development Environment
USB	Universal Serial Bus
GUI	Graphical User Interface
DACPV	Dense Array Concentrator Photovoltaic
RCA	Radio Corporation of America

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CHAPTER 1

INTRODUCTION

1.1 Background

The introduction of the use of high efficiency multi-junction solar cells in the non-imaging dish concentrator (NIDC) has encouraged the research of alignment method of higher efficiency over the years. In order to achieve the optimum working capability of the multi-junction solar cells, the alignment of images from the facet mirrors has to be as accurate as possible. However, the alignment has always been too difficult to be achieved due to many factors.

Firstly, the NIDC consists of numerous facet mirrors, where each of them reflects the image and delivers the solar illuminations to a common target. This becomes challenging as, in order to superimpose the illuminations from every mirror onto the target, all mirrors have to be precisely aligned to achieve maximum possible solar concentration ratio and uniform flux distribution on the target, which has claimed to be a tough task to precisely align a large amount of facet mirrors.

Due to human error, the images as seen from human eyes cannot judge the matching level of the superimposed images accurately. The traditional alignment method proposed by researchers were on-sun single facet mirror alignment, mechanical alignment and optical alignment.

These methods, however, are not practically feasible, as they possess at least a minimum of unavoidable alignment mismatch. Researches have been carried out over the year to find out a better alignment method, which reduces the alignment mismatch to minimum, and the objective is to achieve an alignment method with a negligible mismatch.

1.2 Rationale for the Research

When the alignment outcome is not acceptable, the solar flux distribution on the receiver that is reflected from each facet mirror is not uniform. As a result, the Dense Array Concentrator Photovoltaic (DACPV) module at the receiver will not perform optimally due to the current mismatch caused by non-uniform flux distribution. This will eventually cause the DACPV's electrical performance to drop, and shorten its lifespan.

Due to the problems stated, the study of this project has been proposed. This project tends to establish a solution which can minimize the problem and error caused by the non-uniformity of solar flux distribution.

1.3 Aims and Objectives

As the project title implies, the aim of this project is to design and develop an optical alignment approach for NIDC using target reflection technique.

The research objective of this project is to design an image processing algorithm to determine the centre point of facet mirror. Other than that, this research project is to evaluate the feasibility and practicality of this newly proposed optical alignment method.

This technique contains an acceptable range of tolerance in term of accuracy, However, as the computer intelligence is being utilized, it can provide a precise computational algorithm than the human method. This technique was tested in a practical situation using the real NIDC built beforehand.

Methodology in details of the algorithm used and the output obtained from the experimental results are discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 Review on Mirror Alignment Methods

Unlike conventional parabolic dish, the NIDC contains multi-faceted mirrors to reflect and superimpose the sunlight onto a common target, which is a solar cell. Figure 2.1 shows a large-scale NIDC structure built for the research of this field, whereas Figure 2.2 shows the schematic diagram of sunlight ray reflection on the NIDC.

Figure 2.1: The NIDC Structure

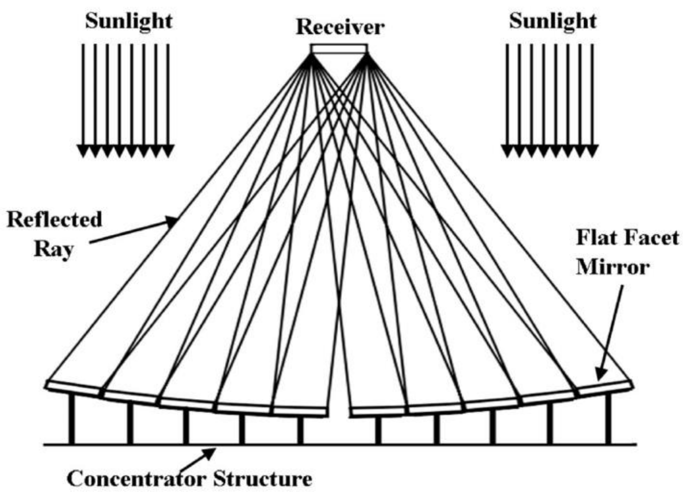

Figure 2.2: Schematic Diagram Illustrating the Reflection of Sunlight Ray on NIDC

In order to maximize the working efficiency of the solar cell, researchers have been finding out the best way to align mirrors for different types of solar concentrator. However, in practical situations, the experimental results show at least a little fluctuation compared to expected result, mainly are due to human error. The traditional alignment methods are classified as on-sun single facet mirror alignment, mechanical alignment and optical alignment.

For the on-sun single facet mirror alignment method, a single facet mirror is aligned initially then followed by the alignment of other mirrors. This technique requires precise sun tracking system to ensure the existence of sunlight ray incident on the mirrors. When one mirror is being aligned, the rest of the mirrors have to be covered to prevent the light spot reflected by them interfere the current adjustment. This method is unpractical for large scale dish concentrator due to its time consuming and difficulties.

For mechanical alignment, the theoretical tilt angle for each mirror was calculated, and then the tilting angles of these mirrors were set by an inclinometer through the manufacturing process in the industry. The inclinometer that is used to contact with the mirror during the alignment process may cause harmful abrasion on the mirror surface.

This research project focuses on the optical alignment method. Optical alignment method utilizes optical devices, such as camera, lasers etc. to align the mirrors. Some optical alignment methods proposed by the researchers are discussed next.

2.2 Using Two Lasers and Apparatus Approach

Diver (2003) proposed an optical alignment method by using 2 laser sources and apparatus to align facet mirrors on solar concentrators. Two laser sources are installed on the solar concentrator, one adjacent to the target board, whereas the other adjacent to the vertex of the optical axis of the concentrator. Both sources are installed in such a way that they are at the centre point of the solar concentrator.

The first laser beam is projected onto the chosen facet mirror, then, at the point where the reflected beam strikes on the target board, the second laser beam is projected onto it. The facet mirror is constantly adjusted until the first reflected beam aligns with the second reflected beam, and the alignment is repeated for every facet mirror. For higher accuracy, a computer is implemented to control the projection of laser more precisely, and to adjust the facet mirror by using an associated steering mechanism synchronized with the mirrors. The method is visualised in Figure 2.3 (Diver 2003).

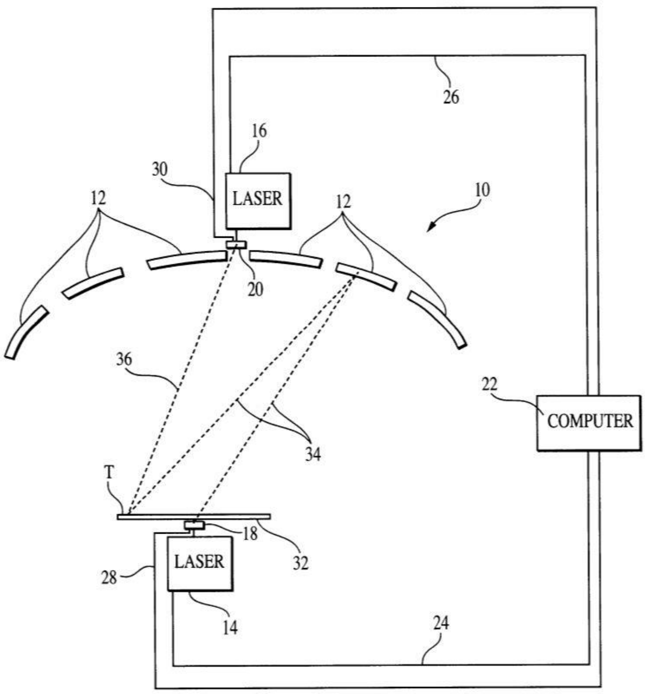

Figure 2.3: Alignment Method Using Two Lasers and Apparatus (Diver 2003)

This method is able to achieve very accurate alignment as it uses the laser beams to determine whether the mirror are matched, using the law of reflection of light. However, the main drawback of this method is that, it can be a little inaccurate, as this method requires the human eye to maintain at the same level of viewing for every alignment. This parallax error is hard to avoid, as the spectator must judge himself with his bare eyes, whether the laser beams are in line with each other.

2.3 Using Theoretical Overlay Photographic (TOP) approach

The TOP approach, as the name implies, utilizes a digital camera and image processing algorithm, to compare whether the source image is overlaid with the target image. This optical alignment method was also proposed by Diver and Moss (2007), to align on the parabolic trough solar concentrator.

Basically, a parabolic trough which consists of 5 mirrors in 4 rows were used in the research by Diver and Moss. For every centre gap in between 2 mirrors for each column, a paper with colour mark as shown in Figure 2.4 (Diver and Moss, 2007) was pasted.

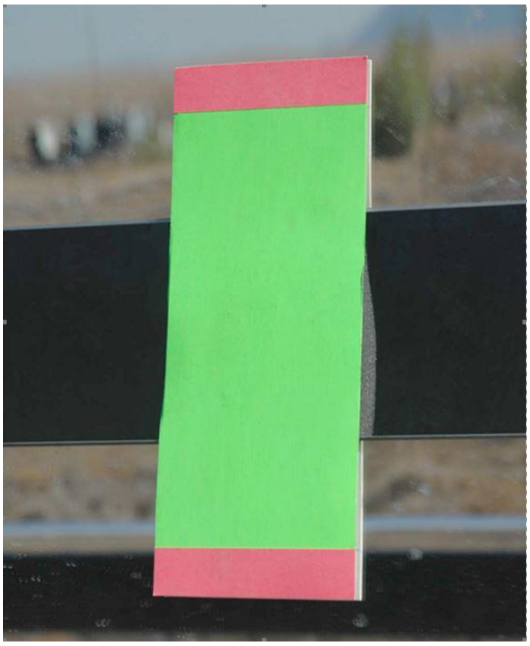

Figure 2.4: Paper with Foam Pad at the Back Squeezes in the Centre Gap at Each Column (Diver and Moss, 2007)

The green mark, which contrasts from the red mark is drawn in such a way that, it is hidden away from the camera when the Heat Collection Element (HCE) is on axis. A bracket is used to mount five cameras, in a vertical manner, as shown in Figure 2.5 (Diver 2007).

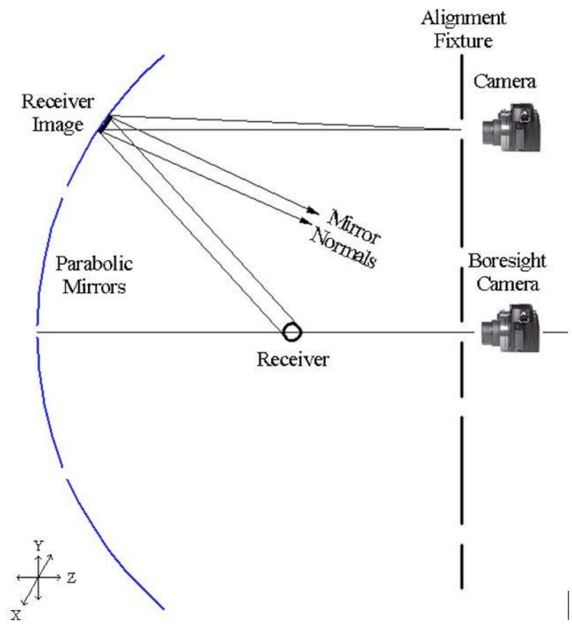

Figure 2.5: Schematic Layout of the Setup of TOP Alignment (Diver, 2007)

The "boresight" camera is used to ensure that the centre camera, HCE and trough are aligned with each other. Then, each camera on the fixture is aligned accurately with the centre of the respective mirror. The mirrors are then aligned properly by adding shim washer to the side of the mirror in the direction that the image needs to be moved, so that the image of the HCE receiver aligns properly, as illustrated in Figure 2.6 (Diver and Moss, 2007).

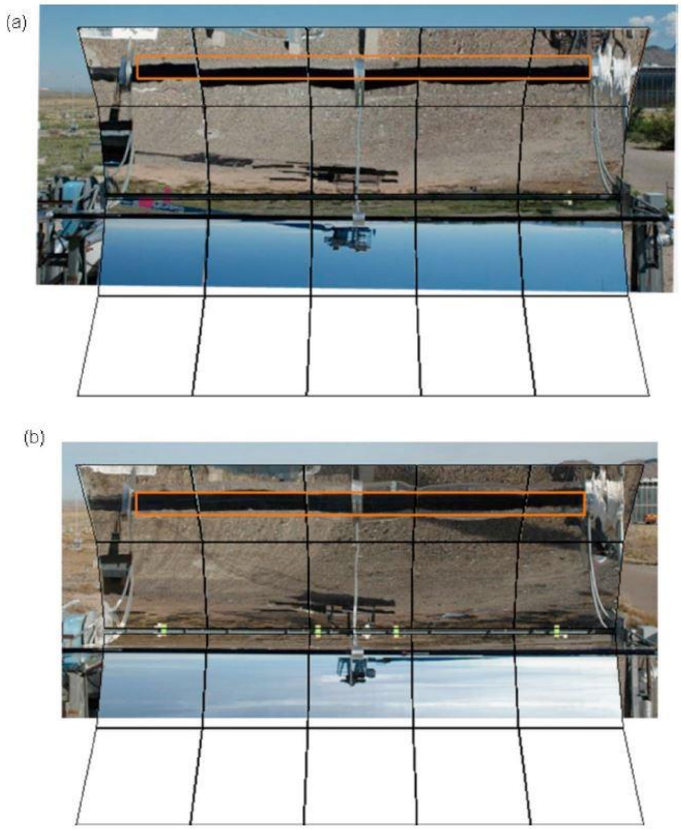

Figure 2.6: Trough before TOP Alignment as Shown in (a), Trough after TOP Alignment as Shown In (b) (Diver and Moss, 2007)

The TOP alignment method is more accurate than the two lasers method, as it uses the image captured by the camera to determine whether the image of HCE are aligned in each mirror. However, this method still lacks a little accuracy, because the images still need to be judged by human eyes to determine if the images are overlaid with the theoretical images, which certainly lacks some accuracy.

CHAPTER 3

METHODOLOGY

3.1 Overview of Research Methodology

The ideas of the research methodology were inspired by the two lasers and TOP approach as reviewed in the previous section.

Each facet mirror on the NIDC is represented in the Cartesian plane as shown in Figure 3.1, and the lens from a camera module in this case is oriented in the direction where the sunlight travels. The camera is to be aligned so that the centre of the image frame from the camera matches with the mirror's centre point, and the mirror is able to be tilted to match its centre point with the target's (receiver's) centre point.

According to the law of reflection, when a sunlight ray strikes at the centre of the mirror, the ray is able to reflect to the target's centre, provided that the three centre points are matched.

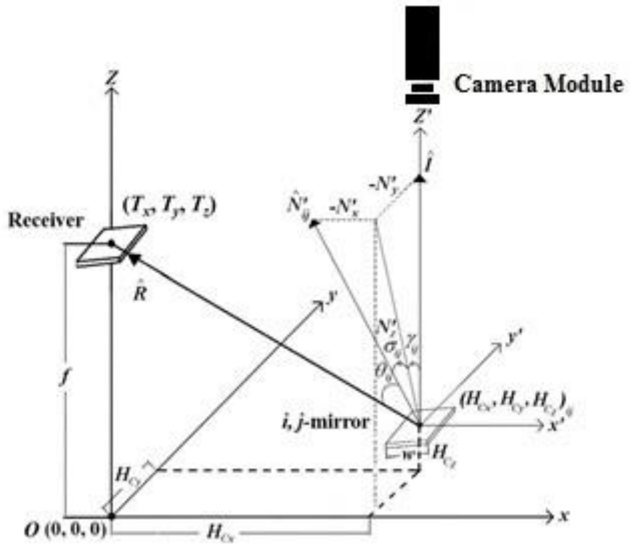

Figure 3.1: Representation of Facet Mirror in the Cartesian plane and Idea of Camera Usage

As the title implies, the target reflection technique utilizes the image reflected from the target to perform alignment, whereby the mirror is tilted to match its centre point with the target's centre point through the image reflected on mirror, as illustrated in Figure 3.2. The system set up for the alignment process is as shown in Figure 3.3.

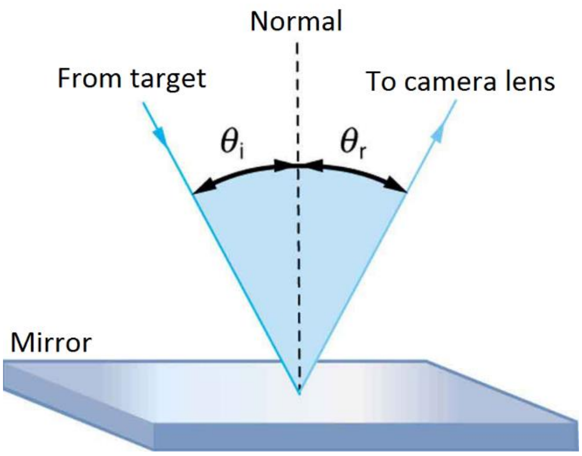

Figure 3.2: Illustration of the Target Reflection Technique

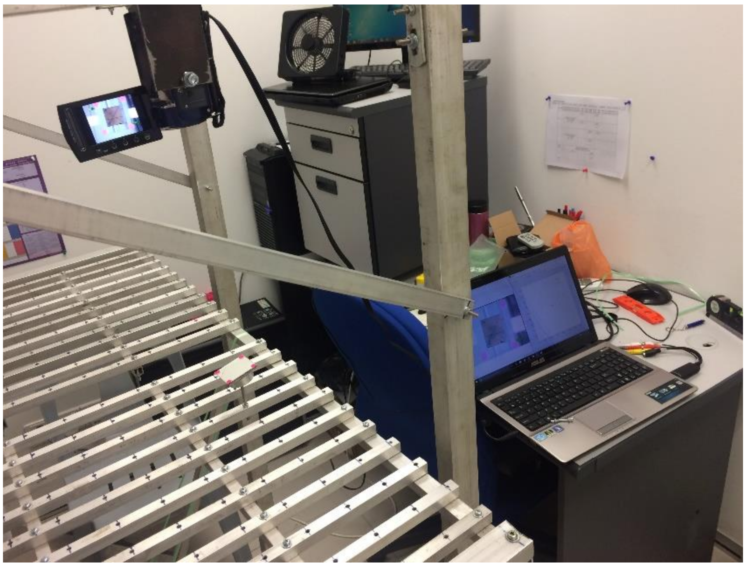

Figure 3.3: System Set Up to Perform Alignment

3.2 System Implementation

The implementation of the alignment system basically consists of the hardware and software part. A working system is required to perform the image acquisition so that the mirror is able to be tilted to match with the target's (receiver's) centre. Before the mirror is tilted, the image acquired by the system is processed by an image processing algorithm written to compute the centre point.

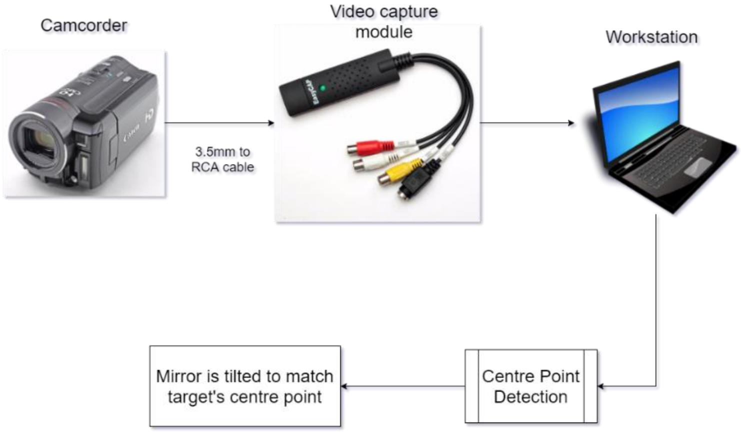

Figure 3.4: Schematic Diagram of Alignment System

The overall hardware implementation for this system consists of the camera module, video capture module, workstation and a self-made gantry to support the camera module.

Hardware implemented carry the role to set up and provide supporting structure to the image acquisition system, and to act as a platform to process the image captured.

3.2.1 Hardware

A camcorder is used as the image capturing device. The camcorder model that is being used in this project is JVC Everio GZ-MG330HUS. The image resolution of this camcorder is 720×480 pixels.

To send the image captured by the camcorder to the workstation, a 3.5 mm to Radio Corporation of America (RCA) cable is used. RCA cable is named after the designer company, which is the Radio Corporation of America, and it is an electrical connector commonly used to carry and transmit audio and video signals. Other than that, a video capture module, known as EasyCap, which is available in the market, is used to connect to the RCA cable. The output of the EasyCap is a USB header. Thus it is connected to the workstation via the USB port.

The workstation acts as the core of the algorithm proposed, in this case a notebook is used. Matlab was chosen as the IDE for the algorithm, due to its user-friendliness and versatility. After the EasyCap has been connected to the notebook, the Matlab is configured to use the camcorder as the image acquisition tool.

3.3 Algorithm of the Alignment

The camera is to be moved to the top of one facet mirror, so that the camera lens is facing the surface of the mirror. Again, the levelling was being checked from time to time.

The colour mark pasted at four corner points of the mirror is detected by the algorithm, and followed by the calculation of centre point of these four corner points. A sample of mirror with pasted colour marks is shown in Figure 3.5.

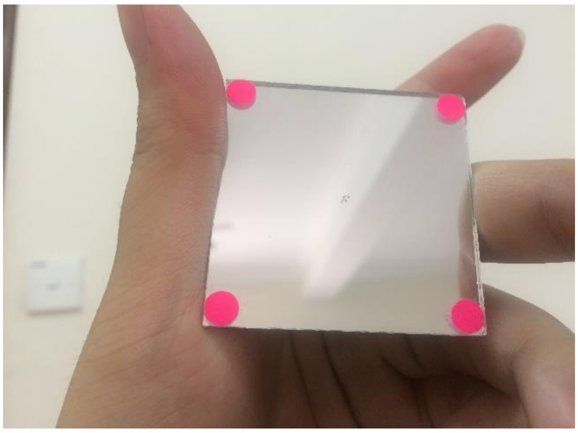

Figure 3.5: Four Corner Points of Each Mirror with Colour Mark

Red colour marks was chosen as the colour is distinct from the surrounding which the camera will be capturing, the algorithm is able to detect and distinguish the red colour more easily. The centre point detection was written in an algorithm manner, for which the blob analysis function in Matlab is utilized. The blob analysis is able to identify centroids for each connected components, in this case which is the red colour marks. The red colour marks are then labelled as the point to represent the corner points of the mirror. Finally, if there are four centroids identified, which means there is four corner points, then the algorithm will compute the centre point using the line intersection method. The algorithm will then make a red cross at the centre point coordinate as an indication. A summary of the algorithm is shown in Figure 3.6.

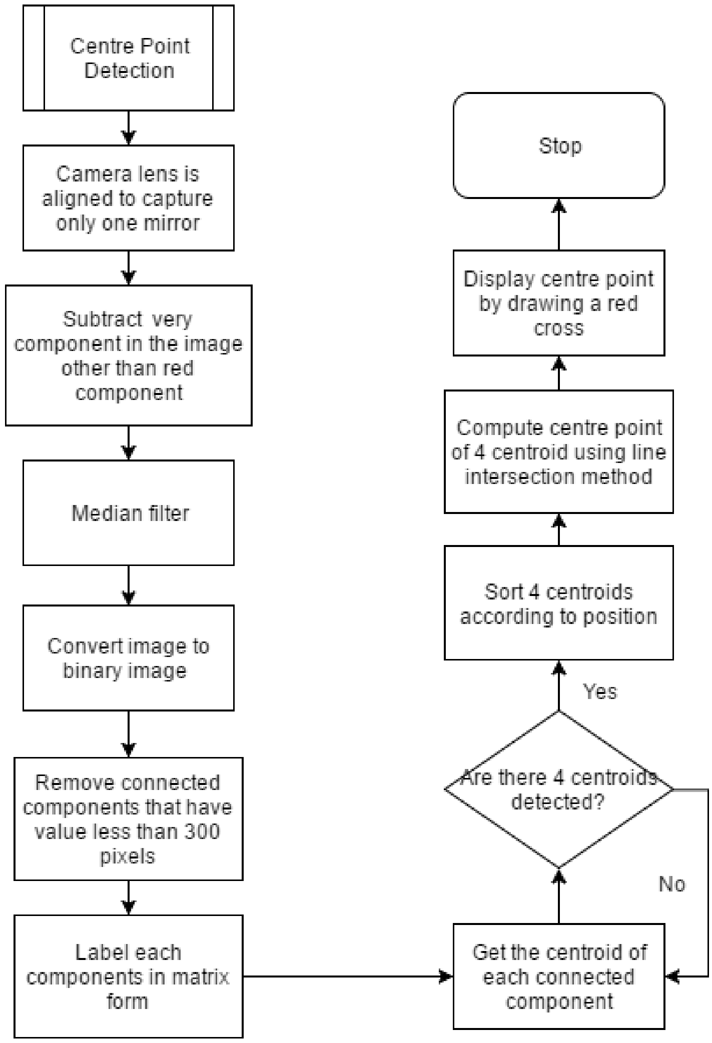

Figure 3.6: Centre Point Detection Algorithm

3.4 Levelling of Target Board and Camera Optical Axis

Before the alignment can be carried out, the target and the camera optical axis are needed to be levelled properly. Since the law of reflection is taken into account, but both the target and the camera lens have to be levelled, so that the accuracy of the point of incident ray and the reflected ray is at the maximum. The target board is levelled as to provide a reference to all mirror for alignment, meaning that, the target board only need to be levelled one time, and then it remains in its level throughout the alignment process.

Several types of leveller have been attempted, including the traditional spirit leveller, digital leveller and the levelling function in a smartphone which utilizes the accelerometer feature. The most appropriate and convenient type of levelling was chosen for target board and camera lens, whereby spirit leveller was chosen to level the target board, as shown in Figure 3.7, and a smartphone leveller was chosen for camera lens.

Figure 3.7: Levelling of Target Board Using Spirit Leveller

The levelling of camera lens has to be checked from time to time, as the structure is moving continuously which may shake the camcorder and cause some misalignment of the optical axis. The camera lens is assumed to have installed on the camera body in such a way that the direction of optical axis is perpendicular from the camera body. Therefore, a smartphone is tied to the camcorder as illustrated in Figure 3.9, and the screen of the smartphone is mirrored to the notebook, as shown in Figure 3.10. The smartphone leveller is calibrated with reference to a flat surface using a digital inclinometer.

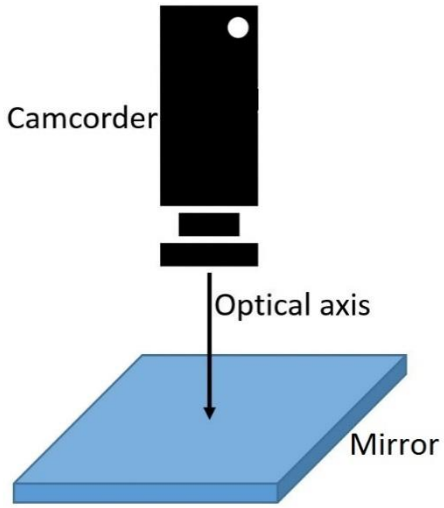

Figure 3.8: Illustration of Optical Axis

The optical axis must be levelled in such a way that it is perpendicular to the target board, as to provide accurate alignment. The levelling of camera optical axis is of utmost importance, as a deviation in the camera optical axis level may cause displacement in the reflected illumination, thereby causing the performance on the solar cell to drop. The concept of optical axis is as illustrated in Figure 3.8.

Figure 3.9: Levelling of Camera Lens Using Smartphone Levelling Function

Figure 3.10: Screenshot of Levelling App in the Smartphone

When the camera has positioned properly, the algorithm will be started. The mirror is then tilted until the reflected image from the target is seen, and then the centre point of the mirror detected is to be matched with the centre point of the target.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Outcome of Alignment

The detected coordinates by the algorithm are represented in the coordinate system. The green circle indicates the image frame centre point, which is halves of the camera lens pixel (X= 360 pixel, Y= 240 pixel). Figure 4.2 shows the Matlab window displaying the detected coordinates and the calculated centre point, whereas Figure 4.3 shows the video frame from the camera with a mapped red cross, which is representing the centre point calculated.

Three points were matched for one piece of mirror: mirror's centre point, image frame centre point and target board centre point. After one piece of mirror has been aligned, the camera is then moved to the next one, and the whole process is repeated until all the available mirrors are aligned. Figure 4.1 shows the NIDC prototype with all prepared mirrors installed on the mirror frame.

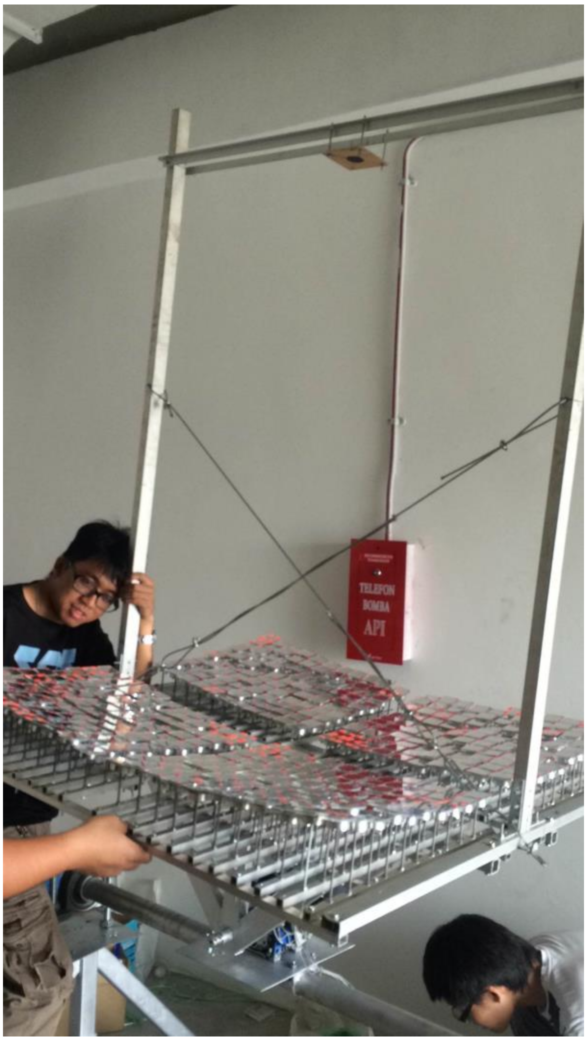

Figure 4.1: Mirrors Pasted with Colour Marks Installed on the NIDC Mirror Frame

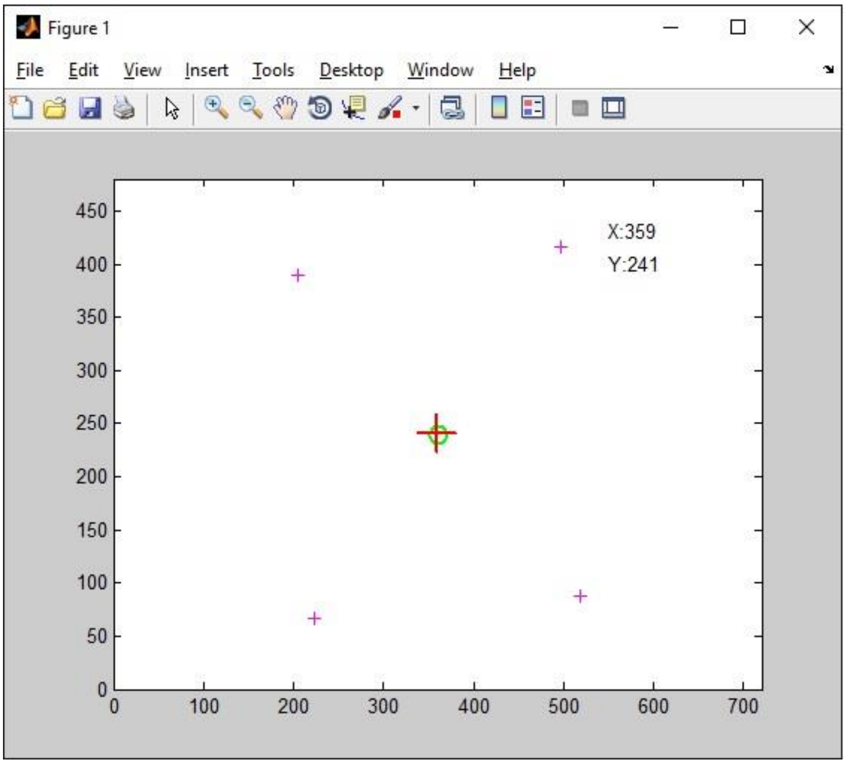

Figure 4.2: Centre Point of the Mirror Indicated as Red '+' Sign

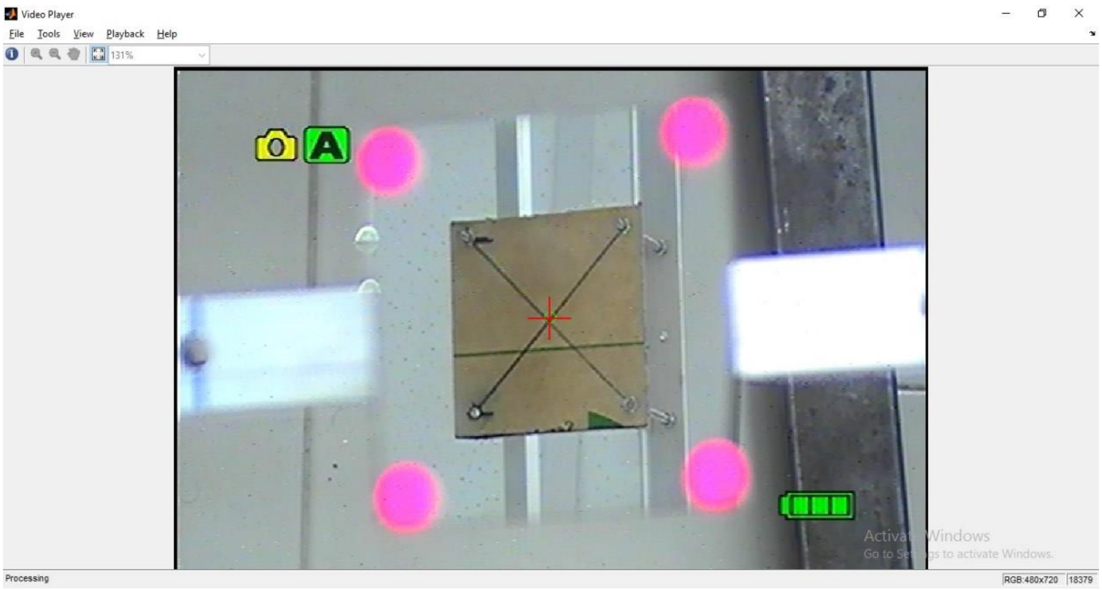

Figure 4.3: Mirror Tilted until the Reflected Image from Target is Seen

The alignment outcome was tested after part of the mirrors have been aligned. Figure 4.4 shows the testing of NIDC at outdoor. From the illumination shown on target board, it shows decent condition of alignment. However, some dispersion of sunlight was observed on the target board, which is not in the centre box drawn. The illumination on the target board is not clear also due to the bad weather condition, where the irradiance is not high enough to produce a good result.

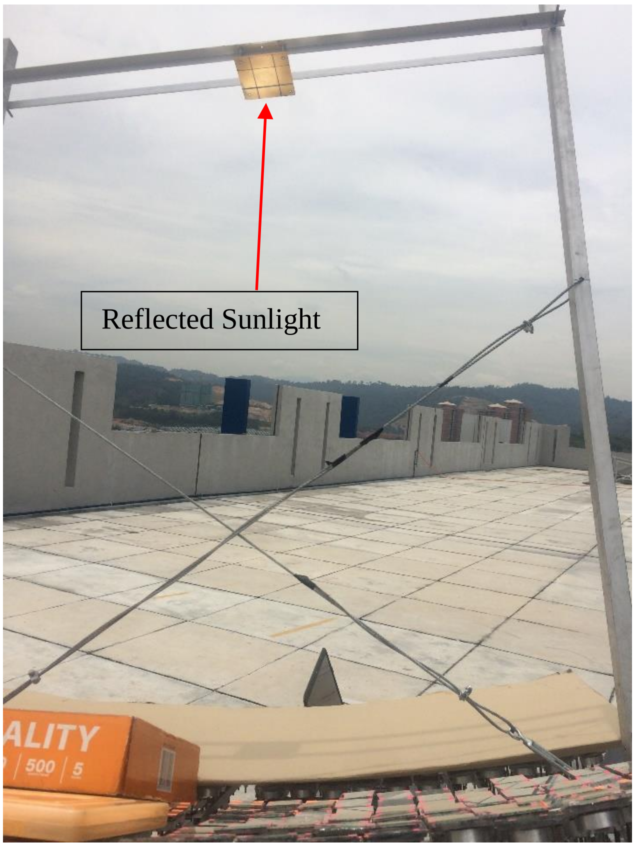

Figure 4.4: Outdoor Test

Other than testing the outcome under the sunlight, the aligned mirror was tested using a laser pen. The laser pen was attached directly to the camera carrier, which is in level with the camera lens. The laser ray emitted corresponds to the sunlight rays, which is perpendicular to the mirror surface. Figure 4.5 shows the setup of indoor laser test, whereas Figure 4.6 shows the magnified view of target board to calculate the displacement of reflected laser.

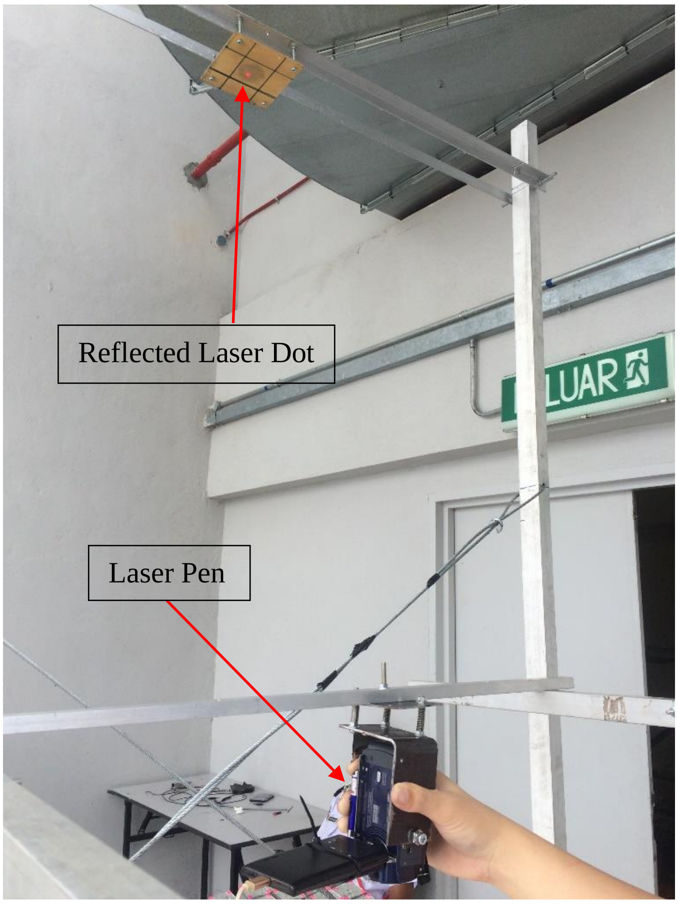

Figure 4.5: Indoor Laser Test (Red Dot on the Target Board Indicates Reflected Laser)

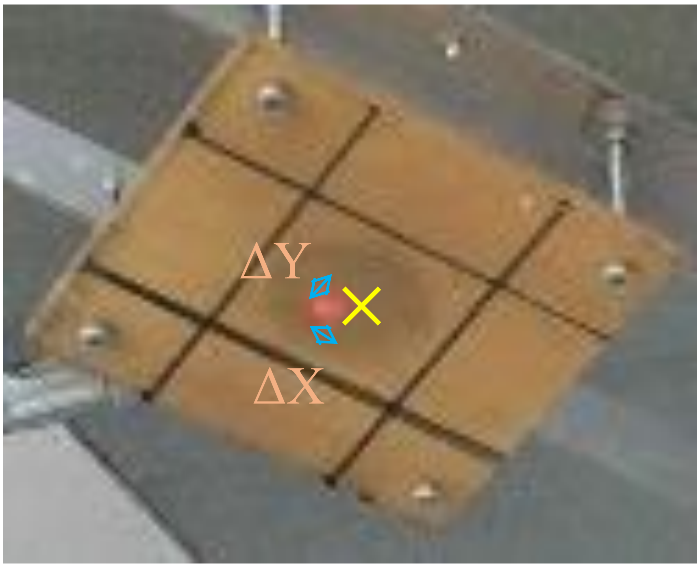

Figure 4.6: Magnified View of the Target Board (Red Dot Indicates Reflected Laser)

After measurement and calculation have been done, it shows that the ΔX and ΔY value are approximate to 0.4 cm and 0.5 cm respectively, which the resultant displacement is approximate 0.64 cm.

According to the law of reflection, the reflected laser ray is supposed to strike on the target centre, provided it is incident on the mirror centre. From the figure shown, it shows that the accuracy of the reflected laser is acceptable, although improvement could be made to increase the accuracy.

4.2 Effect of Levelling Accuracy on Camera Lens

The levelling of camera lens is of utmost importance, as it will affect the location of the reflected sunlight on the target board. Figure 4.7 shows possible camera tilting resulted from levelling error.

The levelling of camera lens is to be checked from time to time, using the smartphone levelling app. The smartphone levelling app provides an adequate level of accuracy, as the sensitivity of the accelerometer in the smartphone is high enough to detect a variation in level.

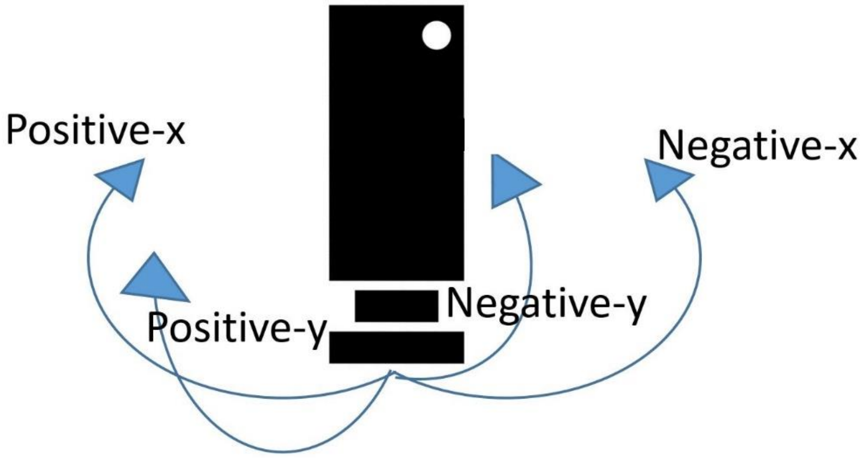

Figure 4.7: Possible Camera Tilting Resulted from Levelling Error

When the camera lens has ran out of levelling, the tilting angle of mirror has to be more to compensate the angle from the tilting of camera. As a result, when the mirror is tilted more than expected, the displacement of the reflected sunlight on the target board emerges.

The direction of displacement corresponds to the direction of tilting angle of camera caused by the levelling error. The amount of angle tilting will cause different in the magnitude of displacement. It can be calculated using equation (4.1)

$$\text{Displacement} = h \tan \Delta\theta \qquad \textbf{(4.1)}$$

where

$\Delta\theta$ = angle of tilting of camera lens, °, and

h = height of target from mirror, cm

Since all the mirrors on the NIDC frame are different in height with respect to the target board, this will affect the magnitude of displacement of reflected sunlight on the target board. There are many heights of the target from mirror, due to the design constraint to prevent the blocking from the adjacent mirrors. The effect of different height on the displacement are tabulated and shown in Table 4.1. The graphs showing displacement for different tilting angle at different height are plotted as shown in Figure 4.8.

Table 4.1: Displacement of Reflected Sunlight for Different Height of Target from Mirror

Height (cm)	*Displacement at different tilting angle (cm)*				
	0.2°	0.4°	0.6°	0.8°	1.0°
120.00	0.42	0.84	1.26	1.68	2.09
117.00	0.41	0.82	1.23	1.63	2.04
114.00	0.40	0.80	1.19	1.59	1.99
111.00	0.39	0.78	1.16	1.55	1.94

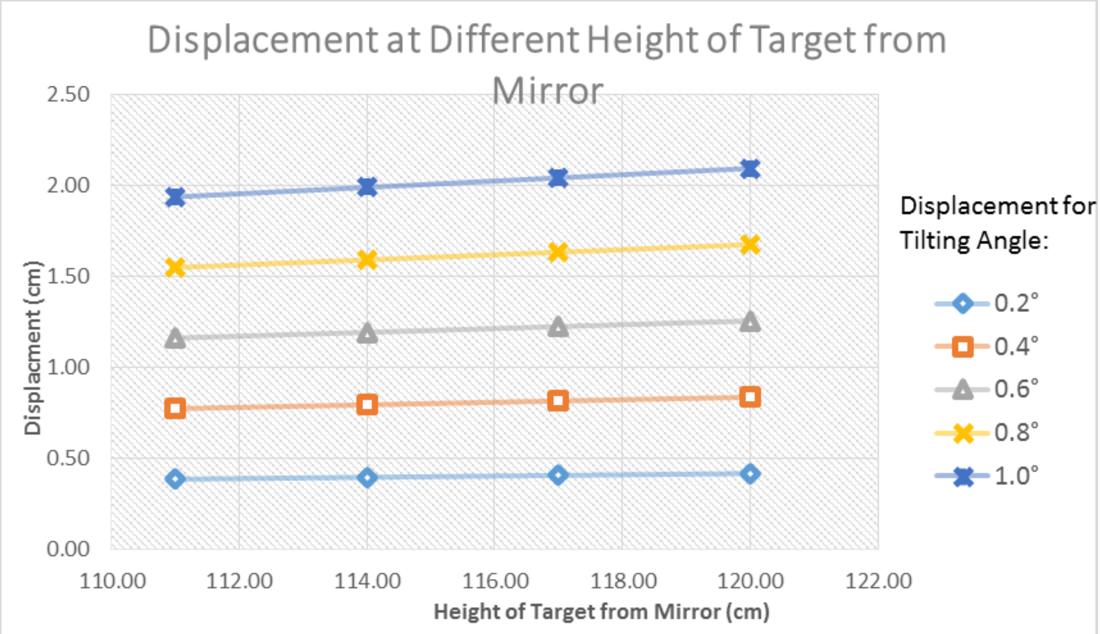

Figure 4.8: Effect of Different Tilting Angle on Displacement of Reflected Sunlight

From the graphs plotted, it is significant that, as the tilting angle ($\Delta\theta$) of the mirror increases, the displacement of the reflected sunlight also increases accordingly. The lowest displacement is 0.39 cm, and the highest displacement can go up to 2.09 cm. It is evident that the error in the levelling of camera lens affects the displacement of reflected sunlight very much.

The data shown has only considered the displacement in single-axis, which is X or Y axis. When the camera level error is in two-axis, the resultant displacement from these two axes has to be calculated using equation (4.2).

$$\text{Resultant Displacement} = \sqrt{(X\text{-displacement})^2 + (Y\text{-displacement})^2} \quad \textbf{(4.2)}$$

The calculated resultant displacement are tabulated and shown in Table 4.2 (taking only the combination of minimum and maximum displacement).

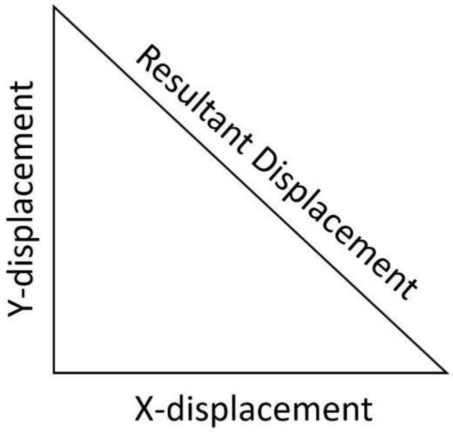

Figure 4.9: Illustration of Resultant Displacement

Table 4.2: Resultant Displacement due to Levelling Error in Two-Axis

***X*-displacement (cm)**	***Y*-displacement (cm)**	**Resultant displacement (cm)**
0.39	0.39	**0.30**
2.09	2.09	**2.96**

When the resultant displacement goes as high as 2.96 cm, the target which is the multi-junction solar cell loses a lot of efficacy, as the illumination has run out of the position in the target very far away. This in turn causes the output from the solar cell drop drastically, as a lot of the illumination is not striking on the target solar cell. Therefore, the levelling error of the camera lens must be kept at minimal to ensure the displacement of illumination on the target does not go too far away.

4.3 Misalignment of Mirror Centre with Respect to Image Frame Centre

When the mirror centre is to be aligned with the image frame centre, the mirror centre coordinates is very hard to achieve exactly the image frame centre coordinate, which is 360 pixels for *X* and 240 pixels for *Y*.

This is caused by the continuous fluctuation of a coordinate point due to the high resolution of the image. The displacement in *X*-pixel and *Y*-pixel are computed using equation (4.3) and (4.4).

$$\Delta X = 360 - X \tag{4.3}$$

$$\Delta Y = 240 - Y \tag{4.4}$$

where

ΔX = displacement in X (in pixel),

ΔY = displacement in Y (in pixel),

X = X coordinate point (in pixel), and

Y = Y coordinate point (in pixel)

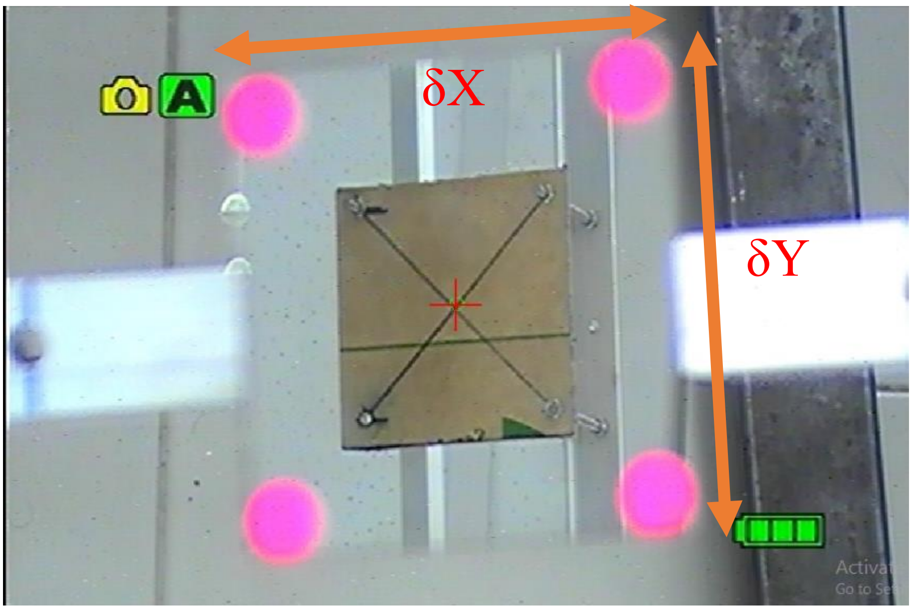

Figure 4.10: Magnitude of Zoom in by Camera will Affect the Displacement

After the displacement in *X*-pixel and *Y*-pixel have been calculated, the displacement of *X*-pixel and *Y*-pixel in centimetre were calculated. The calculation of displacement in *X*-pixel and *Y*-pixel has to consider the how much has the camera lens zoomed in, as indicated in Figure 4.10, value of δX and δY will vary depending on the magnitude of zoom in by camera. The *X*-displacement and *Y*-displacement in centimetre can be calculated using equation (4.5) and (4.6).

$$X\text{-displacement(cm)} = \frac{4}{\delta X} \times \Delta X \quad \textbf{(4.5)}$$

$$Y\text{-displacement(cm)} = \frac{4}{\delta Y} \times \Delta Y \quad \textbf{(4.6)}$$

where

ΔX = displacement in X (in pixel),

ΔY = displacement in Y (in pixel),

δX = amount of X-pixel the mirror has occupied (in pixel), and

δY = amount of Y-pixel the mirror has occupied (in pixel)

The equation shown above has multiplied by four, because the mirror that is used in the NIDC is 4 cm $\times$ 4 cm in dimension. Same as the previous section, the resultant displacement (in cm) caused by the X and Y component is calculated.

Table 4.3: *X* and *Y* displacement at different Δ*X* and Δ*Y*, δ*X* and δ*Y* Pixel Value

δ*X* (pixel)	δ*Y* (pixel)	Δ*X* (pixel)	Δ*Y* (pixel)	*X*-displacement (cm)	*Y*-displacement (cm)	Resultant Displacement (cm)
290	310	-1	-1	-0.014	-0.013	0.019
		-2	-2	-0.028	-0.026	0.038
		-3	-3	-0.041	-0.039	0.057
		-4	-4	-0.055	-0.052	0.076
		-5	-5	-0.069	-0.065	0.094
		1	1	0.014	0.013	0.019
		2	2	0.028	0.026	0.038
		3	3	0.041	0.039	0.057
		4	4	0.055	0.052	0.076
		5	5	0.069	0.065	0.094
300	320	-1	-1	-0.013	-0.013	0.018
		-2	-2	-0.027	-0.025	0.037
		-3	-3	-0.040	-0.038	0.055
		-4	-4	-0.053	-0.050	0.073
		-5	-5	-0.067	-0.063	0.091
		1	1	0.013	0.013	0.018
		2	2	0.027	0.025	0.037
		3	3	0.040	0.038	0.055
		4	4	0.053	0.050	0.073
		5	5	0.067	0.063	0.091
310	330	-1	-1	-0.013	-0.012	0.018
		-2	-2	-0.026	-0.024	0.035
		-3	-3	-0.039	-0.036	0.053
		-4	-4	-0.052	-0.048	0.071
		-5	-5	-0.065	-0.061	0.089
		1	1	0.013	0.012	0.018
		2	2	0.026	0.024	0.035
		3	3	0.039	0.036	0.053
		4	4	0.052	0.048	0.071
		5	5	0.065	0.061	0.089

From Table 4.3, as the δ*X* and δ*Y* value increases, meaning that the zoom in magnitude is larger, the resultant displacement is less. This means that the camera lens has to be zoomed in as much as possible to reduce the error, thus reducing the displacement.

The effect of displacement of reflected image has been discussed in the previous section due to the tilting of mirror. The same theory applies here that, when the displacement from the mirror centre is too big, the mirror has to be tilted more to compensate the displacement, thereby causing some displacement of the illumination on the target.

4.4 Mirror Surface Slope Error

Ideally, the mirror surface is assumed to be at perfect flatness. In a practical situation, due to the technical constraint in the manufacturing process of mirror, the flatness of mirror is not in complete flatness. The illustration of mirror slope error is shown in Figure 4.11.

The typical slope error in a mirror has been reported ranges from 2 to 4 mrad. (Johnston, 1995; Johnston et. al., 1997; Pottler e al., 2005; Marz et. al., 2011).

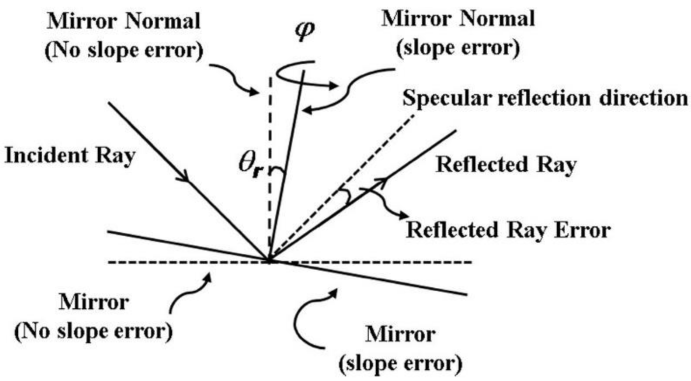

Figure 4.11: Illustration of Mirror Slope Error

The error is in a random number, as the error exists randomly on the surface. The displacement of the reflected sunlight caused by slope error can be calculated using equation (4.7),

$$\text{Displacement} = h \tan \delta \tag{4.7}$$

where

δ = slope error, mrad, and

h = height of target from mirror, cm

Taking the maximum slope error of 4 mrad and height of target of 120 cm, which is the focal length of the NIDC, the displacement calculated is 0.48 cm, which is the maximum possible displacement for the reflected sunlight.

This may have caused the misalignment on the outcome of the alignment, as 0.48 cm in displacement is quite significant in affecting the alignment.

4.5 Overall Discussion on Outcome of Alignment

From the laser test, it shows that the displacement is around 0.64 cm, whereas for the camera level error, the maximum displacement that can be achieved is 2.96 cm from the mirror centre. As for the accuracy error due to misalignment from image frame centre, the maximum displacement is 0.094 cm away from mirror centre, whereas for the error due to mirror slope, it will reach around 0.48 cm.

The only significant error is the misalignment due to camera levelling, for the rest issue, the results are acceptable. However, as long as the camera levelling is kept as close to 0 °for both axes, the error is acceptable.

After due analyses done, this newly proposed alignment is feasible and it is acceptable.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Practicality of New Type of Alignment

As the results have indicated, this alignment method can be concluded as practical to some extent. There are some allowable tolerances during the alignment process, which do not cause significant error. However, there are still some issues that are possibly causing an error, which in turn have caused some significant misalignment at the target.

5.2 Possible Improvement

Throughout this project, there are some issues arose which were not expected during the planning stage. When the project has reached the testing stage, there is a lot more factors which affect the implementation and the outcome.

5.2.1 Software Improvement

The algorithm of the centre point detection can be improved. The current colour mark detection may have some accuracy error due to the RGB value in every pixel of the colour mark region. The blob identified by the algorithm may be different in size, and the identification of centroid may fluctuate. Thus the centre point calculation may not be accurate.

Other than that, the algorithm can be improved by adding another colour detection, which is a colour mark at the target centre. A Matlab GUI can be developed to show whether the 3 points, mirror centre, image frame centre and target centre are matched. The GUI could possibly decide whether the matching of 3 points lie within the allowable tolerance.

5.2.2 System Improvement

A gantry which is used to perform the alignment can be redesigned to overcome many shortcomings, such as camera carrier with very good level handling, structure with maximum stability, and a good frame of the structure that can locate each mirror more easily

In order to ease the alignment process, a closed loop system may be developed, such that the alignment process can be carried out automatically at a maximum precision.

REFERENCES

Diver, R.B. and Moss, T.A., 2007. Practical Field Alignment of Parabolic Trough Solar Concentrators. *Journal of Solar Energy Engineering*, Vol. 129, pp. 153-159

Diver, R.B., 2002. *Alignment method for parabolic trough solar concentrators*. US Patent 6597709 B1

Gary, B. and Adrian, K., 2008. *Learning OpenCV*. First Edition. CA: O'Reilly Media, Inc.

G. Johnston, *On the analysis of surface error distributions on concentrated solar collectors*, J. Sol. Energy Eng. 117(4), 294–296 (1995).

G. Johnston and M. Shortis, *Photogrammetry: an available surface characterization tool for solar concentrators, Part II: Assessment of surfaces*, J. Sol. Energy Eng. 119(4), 286–291 (1997).

K. Pottler, E. Lupfert, G. H. Johnston, and M. R. Shortis, *Photogrammetry: a powerful tool for geometric analysis of solar concentrators and their components*. J. Sol. Energy Eng. 127(1), 94–101 (2005).

APPENDICES

APPENDIX A: Matlab Code

main.m:

```
vid = videoinput('winvideo');
hvpc = vision.VideoPlayer;
src = getselectedsource(vid);
set(vid, 'FramesPerTrigger', 1);
set(vid,'TriggerRepeat',inf);
set(vid, 'ReturnedColorspace', 'rgb')
vid.FrameGrabInterval = 2;

start(vid)

while(1)

    vidRes = vid.VideoResolution;

    data=getdata(vid,1,'uint8');
    hvpc.step(data);
    data = insertMarker(data, [vidRes(1)/2 vidRes(2)/2], 'circle',
'Color','green', 'size',5);
    hvpc.step(data);


    diff_im = imsubtract(data(:,:,1), rgb2gray(data));
    diff_im = medfilt2(diff_im, [3 3]);
    diff_im = im2bw(diff_im,0.18);
    diff_im = bwareaopen(diff_im,300);
    bw = bwlabel(diff_im, 8);
    stats = regionprops(bw, 'BoundingBox', 'Centroid');

    plot(vidRes(1)/2, vidRes(2)/2, 'go', 'MarkerSIze', 10,
'LineWidth', 2);
    axis([0 720 0 480]);
    hold on

    for object = 1:length(stats)
        bb = stats(object).BoundingBox;
        bc = stats(object).Centroid;
```

```
    plot(bc(1),480-bc(2), '-m+')

end


if (length(stats)==4)
    pt1 = stats(1).Centroid;
    pt2 = stats(2).Centroid;
    pt3 = stats(3).Centroid;
    pt4 = stats(4).Centroid;
    centre = (pt1+pt2+pt3+pt4)/4;

    if (pt1<centre)
        point1 = pt1;
    end
    if (pt2<centre)
        point1 = pt2;
    end
    if (pt3<centre)
        point1 = pt3;
    end
    if (pt4<centre)
        point1 = pt4;
    end

    if (pt1>centre)
        point4 = pt1;
    end
    if (pt2>centre)
        point4 = pt2;
    end
    if (pt3>centre)
        point4 = pt3;
    end
    if (pt4>centre)
        point4 = pt4;
    end

   if(pt1(1)>centre(1)&&pt1(2)<centre(2))
       point2 = pt1;
   end
   if(pt2(1)>centre(1)&&pt2(2)<centre(2))
       point2 = pt2;
   end
   if(pt3(1)>centre(1)&&pt3(2)<centre(2))
       point2 = pt3;
   end
   if(pt4(1)>centre(1)&&pt4(2)<centre(2))
       point2 = pt4;
   end

   if(pt1(1)<centre(1)&&pt1(2)>centre(2))
       point3 = pt1;
   end
   if(pt2(1)<centre(1)&&pt2(2)>centre(2))
       point3 = pt2;
   end
   if(pt3(1)<centre(1)&&pt3(2)>centre(2))
       point3 = pt3;
   end
```

```
        if(pt4(1)<centre(1)&&pt4(2)>centre(2))
            point3 = pt4;
        end

        l1=[point1 point4];
        l2=[point3 point2];

        [x,y] = lineintersect(l1,l2);

        if (~isnan(x))
            y =480-y;
            plot(x,y,'r+','MarkerSIze', 20, 'LineWidth', 2)
            text(550,430, strcat('X: ', num2str(round(x))));
            text(550,400, strcat('Y: ', num2str(round(y))));

        end

        midPoint = [x 480-y];
        data = insertMarker(data, midPoint, '+', 'Color','red',
'size',20);
        hvpc.step(data);

    end

    data = insertMarker(data, [vidRes(1)/2 vidRes(2)/2], 'circle',
'Color','green', 'size',5);
    hvpc.step(data);

    hold off

end
```

Line_intersect.m:

```
function [x,y]=lineintersect(l1,l2)

if (~all((size(l1)==[1 4]) & (size(l2)==[1 4])))
disp('You need to provide vectors with one line and four columns')
return
end

try
ml1=(l1(4)-l1(2))/(l1(3)-l1(1));
ml2=(l2(4)-l2(2))/(l2(3)-l2(1));
bl1=l1(2)-ml1*l1(1);
bl2=l2(2)-ml2*l2(1);
b=[bl1 bl2]';
a=[1 -ml1; 1 -ml2];
Pint=a\b;

if (any(Pint==Inf))
disp('No solution found, probably the lines are paralel')
return
end

x=Pint(2);y=Pint(1);

l1minX=min([l1(1) l1(3)]);
l2minX=min([l2(1) l2(3)]);
l1minY=min([l1(2) l1(4)]);
l2minY=min([l2(2) l2(4)]);

l1maxX=max([l1(1) l1(3)]);
l2maxX=max([l2(1) l2(3)]);
l1maxY=max([l1(2) l1(4)]);
l2maxY=max([l2(2) l2(4)]);

if ((x<l1minX) | (x>l1maxX) | (y<l1minY) | (y>l1maxY) |...
       (x<l2minX) | (x>l2maxX) | (y<l2minY) | (y>l2maxY) )
x=nan;
y=nan;
disp('There''s no intersection between the two lines')
return
end

catch err
rethrow(err)
disp('There''s no intersection between the lines (x=nan,y=nan)')
end
```