

# **Reverse Engineering for Measuring Skin Ulcer Size with 3D Scanning**

By

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Dissertation submitted in partial fulfilment of  
the requirements for the  
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# **CERTIFICATION OF APPROVAL**

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A project dissertation submitted to the  
Mechanical Engineering Programme  
Universiti Teknologi PETRONAS  
in partial fulfilment of the requirement for the  
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Approved by:

.....  
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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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## **CERTIFICATION OF ORIGINALITY**

This is to certify that I am responsible for the work submitted in this dissertation, that the original work is my own except as specified in acknowledgments or in footnotes, and that neither the thesis nor the original work contained therein has been submitted to this or any other institution for a degree.

..... (Signed)

..... (Date)

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## **ABSTRACT**

Reverse engineering is developing at a very fast rate nowadays and can be applied in several fields. Reverse engineering can be machine, manufacturing, biomedical engineering and the list goes on. In clinical and research application, the assessment of skin ulcer size has become essentially importance to monitor and evaluate the progress of healing of the wound. Therefore, quantitative measurement, like volume, surface area and depth of a skin ulcer is to be measure to for accessing the progress and effectiveness of healing. The development of non-invasive method of assessing skin ulcer is becoming more and more popular due to the fact that it overcomes the disadvantages that cause by invasive method which is infection and pain. This project involves reverse engineering to facilitate the assessment of the skin ulcer size by using 3D laser scanning method. The development of a MATLAB algorithm which is capable to detect the ulcer from a laser scanning and estimate the quantitative measurement of a skin ulcer from the scanning. Other than that, the algorithm developed also has to be precise in order to achieve the objective of monitoring the changes in skin ulcer. The outcome of this project will significantly simplify and speed up the process of determining the change of a skin ulcer and thus help the clinical personnel in providing more effective treatment regime. Preliminary analysis of the results indicates an overall error and standard deviation of less than 10% of the algorithm performance when compare to invasive method.

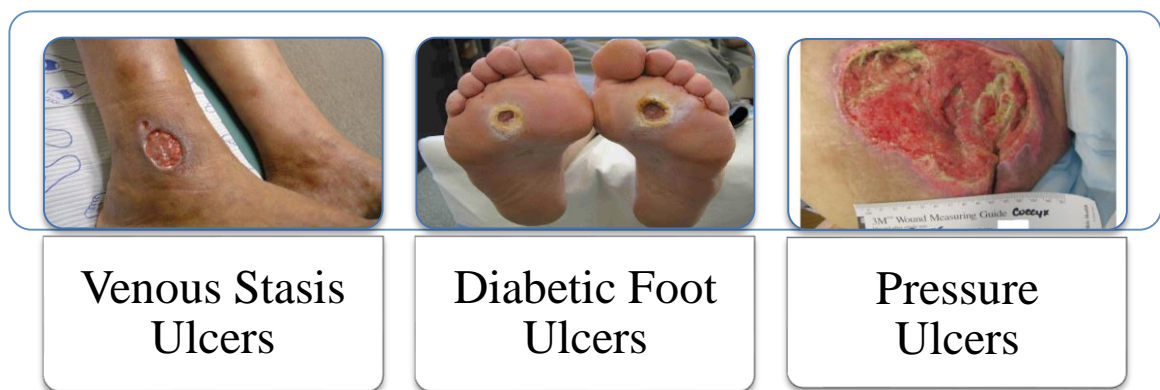
# CHAPTER 1

## INTRODUCTION

### 1.0 INTRODUCTION

An ulcer is an open wound on the skin usually together with the disintegration of tissue and impeding healing. Ulcers can result in complete loss of the epidermis and often accompanied by pain and discomfort to the patient. External ulcers commonly appear on the skin of the lower limbs. An ulcer that appears on the skin is often visible as an inflamed tissue with an area of reddened or, in worse cases, blackened skin. Generally, skin ulcer can be caused by a lot factors. However, the main cause for most of the ulcer cases is due to the poor blood circulation. Other than that, chronic wound can also cause ulcer to a person.

For this final year project, our main type of skin ulcers to be analyzed in the leg ulcers. The commonly found types of ulcers on the body, mainly on the legs, are venous stasis ulcers, diabetic foot ulcers and pressure ulcers. Venous stasis ulcers are also known as leg ulcers as they usually occur on the leg area of the patients. Example of the skin ulcers are shown in Figure 1.



*Figure 1: Common types of skin ulcers.*

The healing of a skin ulcer takes a very long time and has several phases. The first phase of the wound healing right after the wounding is inflammation, which usually last for 4 to 6 days under the normal condition. The main processes of inflammation are

vasoconstriction, hemostasis and vascular dilatation with increased capillary permeability, chemotactic growth factor and phagocytosis. 4 or 5 days after the wounding, the second phase of wound healing starts, this could last for few weeks under healthy healing process. It is the most important event in the process of wound healing. The main processes in this phase are angiogenesis, granulation tissue formation, re-epithelization, and extracellular matrix formation. Tissue formation phase also known as proliferative phase. Eventually, a continuous process of dynamic equilibrium between the synthesis of new stable collagen and the lysis of old collagen is take place. The process is called tissue remodeling phase and can take up to two years. Lower limb ulceration tends to be recurrent and becomes a chronic wound if the wound does not heal in an orderly stage and the estimated period.

## **1.1 BACKGROUND**

The impact of pressure ulcers on the patient, the providers who try to prevent these wounds and the payers for health care has been underestimated for years. Therefore, the National Pressure Ulcer Advisory Panel (NPUAP) has declared that November 16 is Pressure Ulcer Awareness Day. Over 2.5 million US residents develop pressure ulcers (more than patients who develop cancer) every year according to Dr. Aimée Garcia, NPUAP President. There are over 2 million of patients that are suffering from pressure sores and ulcer in Europe [1]. These people are mainly old people with the average age of 74 years old. On the other hand, according to World Health Organization (WHO), there are between 5000 to 6000 cases of Buruli ulcer, another type of skin ulcer, reported annually from 15 countries around the world. Although medical treatment and health care are very common nowadays, the cost for wound care is still very expensive. This is because for a wound to be completely healed, it requires at least several months of time. For instance, pressure ulcers cost \$9.1 billion to \$11.6 billion per year in the United States with the cost for individual patient care ranging from \$20,900 to \$151,700 per pressure ulcer [2]. In some cases, wounds can take up to two years to heal. Furthermore, there are a wide variety of method and medicine that can be used to treat skin ulcer. Thus, the monitoring of the condition of skin ulcer plays a very important role in ulcer treatment and allows better chance of faster recovery for most patients.

## **1.2 PROBLEM STATEMENT**

Monitoring wound healing progress turn out to be essential due to the fact that ulcers are hard to heal. To monitor the healing progress, the quantitative measurement of the ulcer must be assessed. The most objective ways to assess the healing progress of a skin ulcer is to measure the quantitative measurement of the skin ulcer. This quantitative measurement are mainly the volume, area, depth and perimeter of the wound. Invasive method of measuring and assessing the skin ulcer can cause inaccuracy such as overestimation. Other than that, it will also cause infection and disturbance to the wound. Invasive method will also cause pain to the patients. To obtain the quantitative measurement of the skin ulcer, non-invasive method proves to be a new and effective way to assess the size ulcer size. However, from the previous work that has been done, we need to obtain a point cloud of the scanning and reconstruct a 3D solid from the point cloud in order to assess the size of the wound. The current available method is considered as tedious and complex. This will require more effort and time for the assessing of skin ulcer. Other than that, there are also method developed by previous researches that requires user to define the boundary of the ulcer manually. This method can be simpler compared to other method but the precision of the measurement is low. All of the weak points mentioned will be further discussed in the literature review, in CHAPTER 2. With all problems that we might face in assessing a skin ulcer size, the questions that arise here are “how to make the process of assessing skin ulcer size to be simpler?” and “how to assess the skin ulcer size with high precision?”

## **1.3 SIGNIFICANCE OF THE PROJECT**

The significance of the project is to develop a MATLAB skin ulcer assessing algorithm that can:

- a) Estimate the quantitative measurement (volume and area) of a skin ulcer by non-invasive method.
- b) Compute the curvature parameter of the scanned surface.

- c) Automatically carry out the segmentation for the region of interest (ROI) based on the curvature parameter.
- d) Maintain the precision of the result for skin ulcer monitoring purpose.

#### **1.4 OBJECTIVES**

The main objective of this project is to measure the quantitative value of the skin ulcer by using reverse engineering. This project will involve the development of a MATLAB algorithm to estimate the desired quantitative measurement of the skin ulcer based on input of point cloud from laser scanning. The main quantitative value to be measured is the volume of the ulcer. Next, the measurement of area of the ulcer serves as an aid to help analyze the condition of an ulcer.

The sub-goal of this project is to maintain the precision of the result so that it can be utilized for monitoring the healing progress of the skin ulcer.

#### **1.5 SCOPE OF STUDIES**

To achieve the objectives of this project, the scope of study are:

- a) To conduct study on previous works and literatures on non-invasive method of assessing skin ulcer size.
- b) To conduct training on the handling and operation of 3D laser scanner.
- c) To carry out the experiment by using 3D laser scanner on skin ulcer model.
- d) To develop MATLAB algorithm that can calculate the curvature of the scanned surface and segmentation for the region of interest.
- e) To develop MATLAB algorithm for estimating the quantitative measurement of skin ulcer.
- f) To carry out experiment using invasive method by applying relevant theories and principle of applied physics and science as a comparison to the current work.

## CHAPTER 2

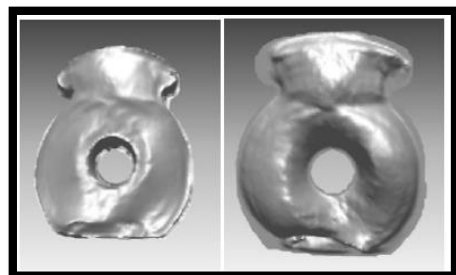
### LITERATURE REVIEW

#### 2.1 REVERSE ENGINEERING

According to [3], reverse engineering is the process of analyzing a system or object to identify their components and relationships and create representation of them in another form. Reverse engineering often involves the exploration and understanding of the original object by disassembling and analyzing a target object or system. Sometimes, 3D scanning and 3D reconstructing of an object can be also related to reverse engineering process. The process of reverse engineering is evolving at a very fast pace and is being implemented in many fields nowadays. Example of application of reverse engineering can be found in software, machine, biomedical and also manufacturing industry. For instance, reverse engineering is being applied in the studies to reconstruct object with specular metallic surface by [4], the result are as shown in Figure 3. Another example of reverse engineering process is the scanning of an engine part and converting the scanning into CAD model as shown in Figure 2.



*Figure 2: Reverse engineering of an engine part.*



*Figure 3: Reverse engineering of a glass bottle.*

In biomedical engineering field, reverse engineering is often used in determining and monitoring the condition of a patient. In this field, both the medical doctors and also the engineering usually work hand-in-hand to widen possibilities for reverse engineering to be applied. For instance, reverse engineering is being used for early diagnosis of Alzheimer by using brain magnetic resonance imaging (MRI) image. Other than that, it is also being used to monitor the conditions of the wounds on a patient [5].

## 2.2 ULCER ATTRIBUTES




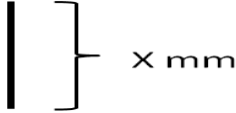
Ulcers can appear in various shapes with different sizes such as round, ellipse or even an almost rectangular shape. Each type of ulcer has a different diagnosis and is classified based on the location and the wound shape. According to [8], we can describe the ulcer wound with several wound attributes which are shown in Figure 4. In addition, each attributes can be further described with the descriptor shown in Table 1. Wound attributes can be classified into four classes, which are wound boundary, wound edges, wound base, and wound depth. In each attribute, the descriptor is introduced to further assist in the wound assessment.



Figure 4: Schematic diagram of ulcer attributes.

Attributes	Descriptor	Schematic
Boundary	Regular	
	Irregular	
Edge	Sloped	
	Punched Out	
	Undermined	



Base	Elevated	
	Homogenous	
	Depressed	
Depth	Unit (mm)	

*Table 1: Common wound attributes, descriptor and their schematic diagram.*

### 2.3 MEASURING SKIN ULCER SIZE

Traditionally, doctors examine the condition of a skin ulcer on a patient by visual inspection. However, this method is very inaccurate and may result in misdiagnosis. With the high amount of patients that a doctor need to attend to in a single day, averagely 22 to 27 patients per day, the chances for the doctor to give out the wrong prescription are relatively high [6]. Measuring a skin ulcer size can be very vital in assessing the condition of a wound on a patient. This is because the development of skin ulcer size reflect the effectiveness of the treatment and healing condition of the ulcer. Skin ulcer patient is often filled with the feeling of depression. Failing to determine the progression of a skin ulcer will lead to ineffective treatment and eventually causing economical and psychological distress to a patient. To measure the condition and progression of an ulcer with high precision, the quantitative values of the ulcer should be measured and compared from time to time. Skin ulcer quantitative value are the volume, depth, true surface area and top surface area. Being able to measure these value with high consistency will greatly aid the clinical personnel to evaluate the effectiveness of a certain regime. There are mainly two type of method to obtain the quantitative measurement as mentioned, namely invasive method and non-invasive method.

### 2.3.1 INVASIVE METHOD

One of the conventional methods of assessing skin ulcer healing is by visual inspection of the tissue in the skin ulcer. Other than that, invasive method is also used to measure the volume, depth and area of the ulcer. Volume of the ulcer is measured by several methods. The method are as below:

- Saline or alginate paste (volume)

Saline or alginate paste is used to fill the wound by calibrated syringe and the volume is measured [7]. This method can be inaccurate due to the absorption of saline by skin and overflow problem. This method is as shown in Figure 5.

- Ultrasound (volume)

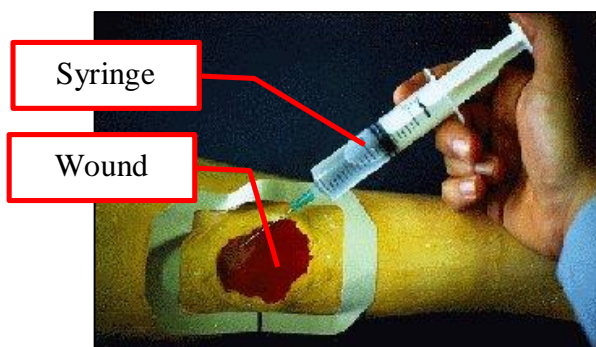
Ultrasound scanning can be used to access the volume of an ulcer. This method is considered as one of the invasive method because the ultrasound scanning requires a physical medium through which it can travel. Therefore, the wound have to be filled with gel and then covered with a film dressing prior to the scanning [8].

- Moistened cotton tip (Depth)

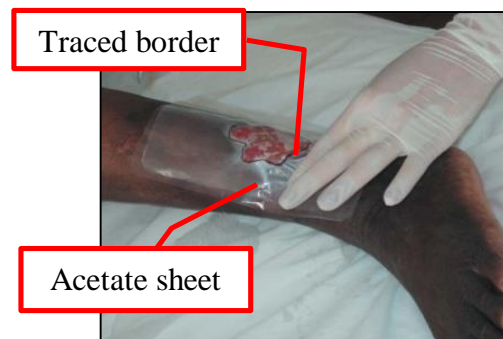
In order to measure the depth of the wound, a moistened cotton tip is placed into the depth of the wound and marking the healthy skin level [9].

- Cartesian acetate sheet (Area)

For measuring the surface area, a Cartesian acetate sheet is to be located into the wound. The example of measuring the area of skin ulcer using acetate skin can be seen in Figure 6.



*Figure 5: Measuring ulcer volume by injecting saline.*



*Figure 6: Measuring ulcer area by tracing with acetate sheet.*

In this project, the result from the invasive method of measuring the skin ulcer quantitative values will be used as a comparison to the main result of the project. The result of the invasive method only serves as a comparison to the non-invasive method experiment and may not be accurate due to the errors and inaccuracy as mentioned previously.

The invasive method that will be implemented for measuring the volume of the skin ulcer model in this project involves the formula of density. The general formula of density is as shown, where,  $\rho$  = density,  $m$  = mass and  $V$  = volume.

$$\rho = \frac{m}{V} \quad \text{-----(1)}$$

The equation then can be rearranged to find the  $V$ , given that the density and the mass is known.

$$V = \frac{m}{\rho} \quad \text{-----(2)}$$

The cavity of the ulcer model will be filled with water in order to get the measurement. The mass will be measure by using an electronic balance with sensitivity up to 0.01g. The difference between the initial mass and the final mass of the ulcer model will be weighted and calculated with the equation below in order to get the volume of the ulcer.

$$m = m_f - m_i \quad \text{-----(3)}$$

where,  $m_f$  is the mass of the model after filled with water and  $m_i$  is the initial mass.

According to the Handbook of Chemistry and Physics, CRC press, 64th Ed, the density of Water at 1 atmosphere pressure is shown in Table 2 below [10].

Temperature °C	Density g/cm <sup>3</sup>	Temperature °C	Density g/cm <sup>3</sup>
15	0.999103	22	0.997774
16	0.998946	23	0.997542
17	0.998778	24	0.997300
18	0.998599	25	0.997048
19	0.998408	26	0.996787
20	0.998207	27	0.996516
21	0.997996	28	0.996237

*Table 2: Density of water at different temperature.*

From the table above, we can assume the density of the water to be 0.99 g/cm<sup>3</sup> when it is rounded up in to 2 decimal points.

### 2.3.2 NON-INVASIVE METHOD

Non-invasive method for obtaining the skin ulcer size can basically be divided into three main categories. They are:

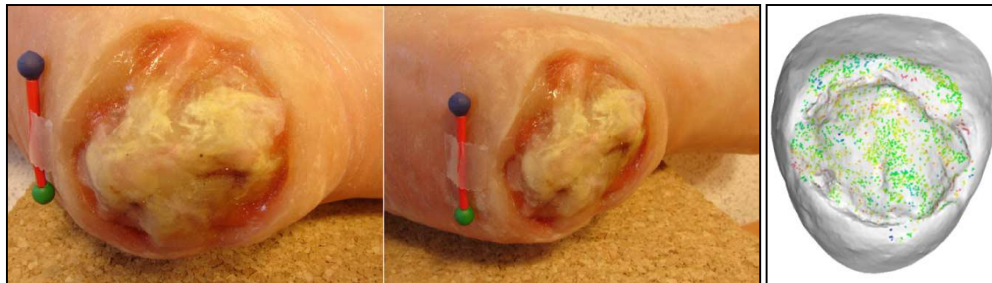
- structured light
- optical photogrammetry or digital imaging
- Laser scanning.

The earliest non-invasive method of measuring the skin ulcer can be traced back to 1995, by Jones, B. F., & Plassmann, P., where they used the colour-coded structured light to assess the skin ulcer [7]. Although this method is categorized in the digital imaging group for non-invasive assessment of skin ulcer, it also involves the triangulation method where the position of a projector and CCD camera is used to calculate the depth of the skin ulcer. Similarly, studies such as [5], [8], [11] and [12] which use laser scanning is also based on the triangulation method.

For laser scanning, both [5] and [11] uses the midpoint projection and convex hull method to produce 3D mesh and solid model from the point cloud that is obtain from the laser scanning. Although the accuracy of the measurement is high, it is not suitable for measuring wounds with elevated base. In year 2003, Callieri, M et. al. develop a new integrated tool, DERMA, which is able to measure and assess the time evolution of chronic wounds [13]. This tool is highly efficient as it can produce different kinds of measurement and comparisons. The latest work on non-invasive method of wounds assessment is published by Fernando, Z. et. al. in 2012. In this work, they used Geodesic Active Contour (GAC) to find the border of a wound prior to measuring the volume of it. Other than that, they also used Taubin filtering procedures to remove high frequency distortions from the point clouds obtained from the laser scanner [14]. Similar to [8] and [11], 3D Delaunay tessellation is also applied to obtain a tetrahedron mesh and hence calculate the volume.

The digital imaging method is being used by [7], [15], [15] and [17] in their researches. Principle of polarization of light is being used in [15]. This method is not really efficiency due to the fact that it needs a lot of pre-processing of raw images. On top of that, they only determine the border of the ulcer which is far away from our objective, to

measure the size of the skin ulcer. For [7], their method of measuring the volume and area of the skin ulcer can be considered as primitive. This is because their work is being done in almost 17 years ago. Nevertheless, the result of their work is still very impressive as they managed to obtain average 3% error for the volume measurement and 2% error for the area measurement. On the other hand, [16] who are using the stereo photogrammetric method in assessing the volume of the skin wounds has a very new technology involved. In the work presented, they used digital camera for the raw data collection. The accuracy of this method is not really high compared to the other laser scanning method as it has a maximum error of 1.25 cm<sup>3</sup>. The ulcer model and the reconstructed 3D model are being shown in Figure 7.



*Figure 7: The model created by S. Treuillet et. al.*

One of the equipment that is commonly used in stereo photogrammetric method for reverse engineering is Kinect sensor, a motion sensing input device by Microsoft. Example of 3D reconstruction using Kinect are in [18].

Example of the 3D reconstruction using Kinect sensor is as shown in Figure 8.



*Figure 8: Example of 3D reconstruction using Kinect sensor.*

## 2.4 SUMMARY TABLE

The literature review that has been done is summarized in the summary table below.

Researchers	Used Feature	Technique	Advantage/Disadvantage	Result
[13]	Laser Scanning	DERMA	High efficiency can produce different kinds of measurement, store the data and comparisons. Heavy and expensive equipment.	<2% error on linear measures <3% on volumetric measures <5% difference <8% variation
[11] & [12]	Laser Scanning	Midpoint projection and Convex hull approximation	Not suitable for large, elevated based wounds.	<10% error, except for elevated based Precision: 0.994050
[5]	Laser Scanning	Midpoint projection and Convex hull approximation	Not suitable for large, elevated based wounds.	<7% error
[15]	Digital Imaging	Contour Initialization, evolution and Pixel classification	Need a lot of pre-processing, only determine the border of ulcer.	Better compare to Adaptive Thresholding (AT), Gradient Vector Flow (GVF) and Level Set (LS)
[7] & [17]	Digital Imaging	Colour-coded structured light	Precision drops when measuring shallow wounds.	~3% error for volume 2% higher than true area
[16]	Digital Imaging	Stereo photogrammetric	Only need digital camera, simple equipment. Need self-calibration process.	<1.25cm <sup>3</sup> error
[14]	Laser scanning	3D Delaunay tessellation	Simple way of ulcer border segmentation.	<1.2% accuracy error <2% precision error

*Table 3: Summary table for the literature review.*

## 2.5 SURFACE CURVATURE THEORY

MATLAB is applied as computational tool for implementation of algorithms. The binary stl file is being imported into MATLAB and an algorithm to calculate the mean curvature,  $K_m$  of the surface is being developed. The border of the skin ulcer is determined by setting specific value of mean curvature. Region growing is then being performed within the space bounded by the border.

The  $K_m$  of the surface is calculated based on the Coordinate Transformation (CT) method in [19]. The main equation for calculating the  $K_m$  is as below:

$$K_m = \frac{1}{2} \left\{ \begin{bmatrix} E & F \\ F & G \end{bmatrix}^{-1} \begin{bmatrix} L & M \\ M & N \end{bmatrix} \right\} = \frac{1}{2} \frac{EN-2FM+GL}{EG-F^2} \text{ -----(4)}$$

where for surface patch,  $S(u,v) = (u, v, au^2 + 2buv + cv^2)$ ,  $E = 1$ ,  $F = 0$ ,  $G = 1$ ,  $L = 2a$ ,  $M = 2b$ ,  $N = 2c$ . This equation then can be simplified into:

$$K_m = a + c \text{ -----(5)}$$

where a and c are obtained from the projection of point from (x, y, z) to the orthogonal base (u, v, w).

$$Ap = q \rightarrow \begin{bmatrix} u_1^2 & 2u_1v_1 & v_1^2 \\ u_2^2 & 2u_2v_2 & v_2^2 \\ \vdots & \vdots & \vdots \\ u_n^2 & 2nv_n & v_n^2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \text{ -----(6)}$$

And we can find the matrix p from the following equation.

$$[p] = [A^T A]^{-1} [A^T] [q] \text{ -----(7)}$$

The projection of point from (x,y,z) into (u,v,w) is illustrated in Figure 9.

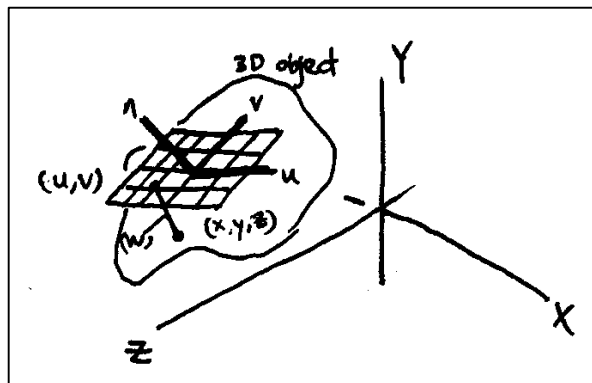
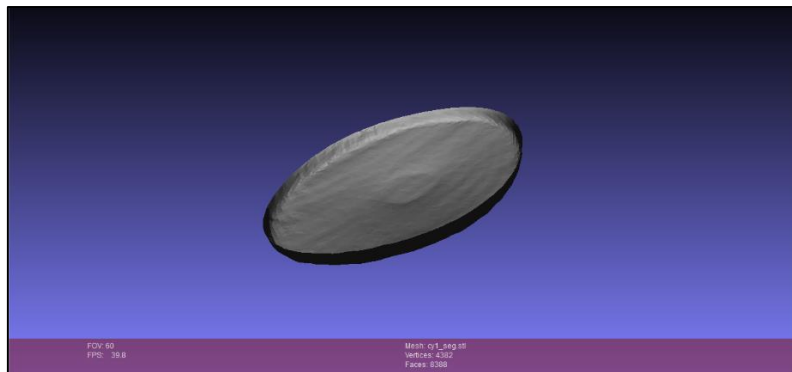


Figure 9: Transforming surface points into local coordinates.

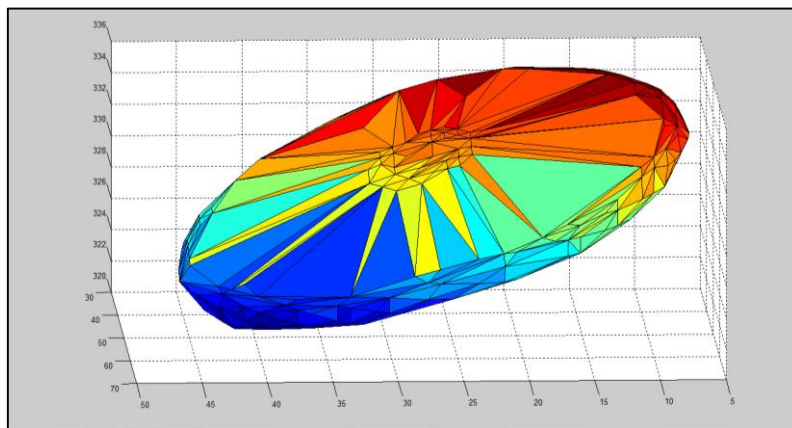
After the segmentation process, the volume and area of the ulcer region is then being calculated with MATLAB predefined convex hull algorithm by using the segmented vertices as input. The output of the algorithm is the volume, area and also the mesh of the convex hull. The theory of convex hull used are similar to [5].

## 2.6 CONVEX HULL THEORY

By performing tetrahedralization, a convex hull or 3D model can be obtained. A tetrahedralization of  $V$  is a set  $T$  of tetrahedra in 3D whose vertices collectively are  $V$ , whose interiors do not intersect each other, and whose union is the convex hull of  $V$ . A Convex Hull,  $CH(V)$  is the smallest polyhedron in which all elements of  $V$  on or in its interior [20] & [21]. Figure 10 and Figure 11 shows the example of the convex hull from the scanning.



*Figure 10: The scanning of model 1.*



*Figure 11: The Convex hull of the scanning.*



## **CHAPTER 3**

### **METHODOLOGY**

#### **3.1 PROJECT METHODOLOGY**

This project starts with the problem statement of the topic. Articles related to the topic are being search from website such as IEEE Explore, sciencedirect.com, Scopus and Athens by using the correct keywords. Keywords that are being used include: skin ulcer, reverse engineering, measurement and laser scanning. With all the papers and articles available, the gap in the field is being determined and stated as the problem statement. All the related materials which are being studied are cited in the references part of this report.

After determining the problem statement, detailed literature review is being carried out to further verify the problem and hence determining the objective of the project. Literature review is also being carried out so that more knowledge about the topic can be obtained. The literature review process should be carried out for a long period of time so that the updates and new technologies can be identified while the project is being carried out. On the same time, the training for laser scanner is being performed so that we are familiar with the instrument, the device and the software for point cloud acquiring. Process such as setup, calibration and configuration of the laser scanner is being taught during the early stage of the training. The scanning training is carried out on random simple object, so that we can know the basic procedures in obtaining point clouds for the object.

After that, models of skin ulcer are being scanned in the laser scanning experiment. From this experiment, the point cloud and facets of the models is to be acquired from the scanning. If the point clouds and facets acquired are not acceptable, contain large holes noise, the scanning process will be repeated until acceptable point cloud and facets is obtained. With the scanning data obtained, a MATLAB algorithm will be developed to estimate the quantitative measurement of the skin ulcer. The process of the estimation will then be tested for the speed and precision. In order for the algorithm to be applied in the project, it has to be faster and maintain a certain level of precision compared to the other algorithm available.

Other than the non-invasive method of measuring the size of the ulcer, an invasive method of measuring the size of the skin ulcer is also being carried out as control for the project. The invasive method of assessment involves the formula of density and other conventional techniques of measuring volume and area. With all the result obtained, both from invasive method and non-invasive method, we can now compare, discuss and make conclusion about the project.

The results of the project is then recorded and compiled into the report. Final presentation about the findings of the project will be given to the supervisor and examiner in the end of the course. The schematic flow diagram of methodology for this project is shown in Figure 12.

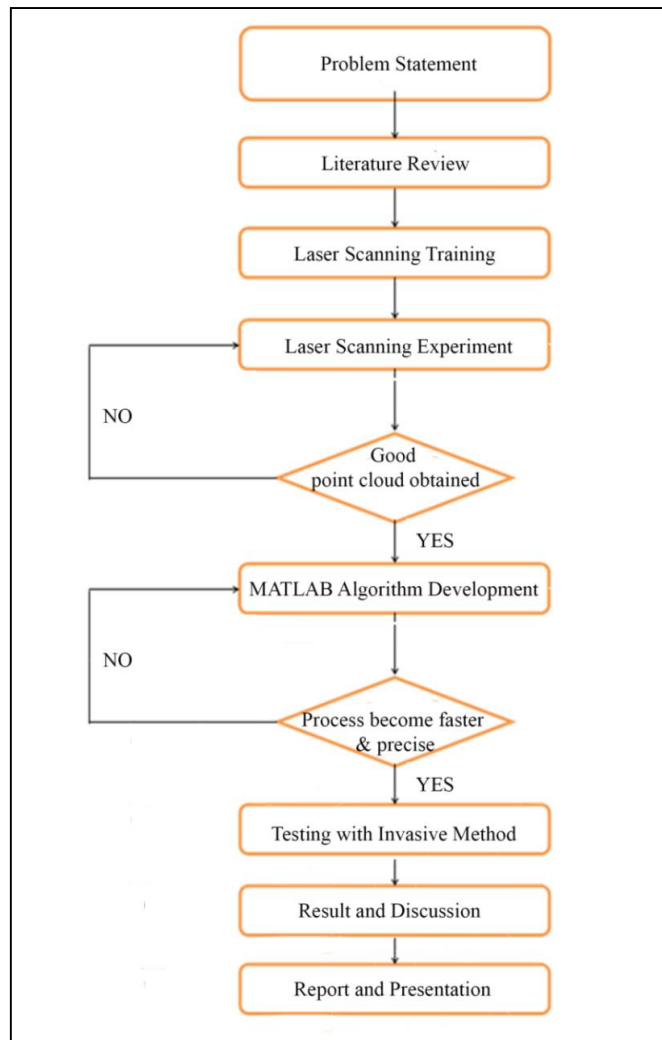
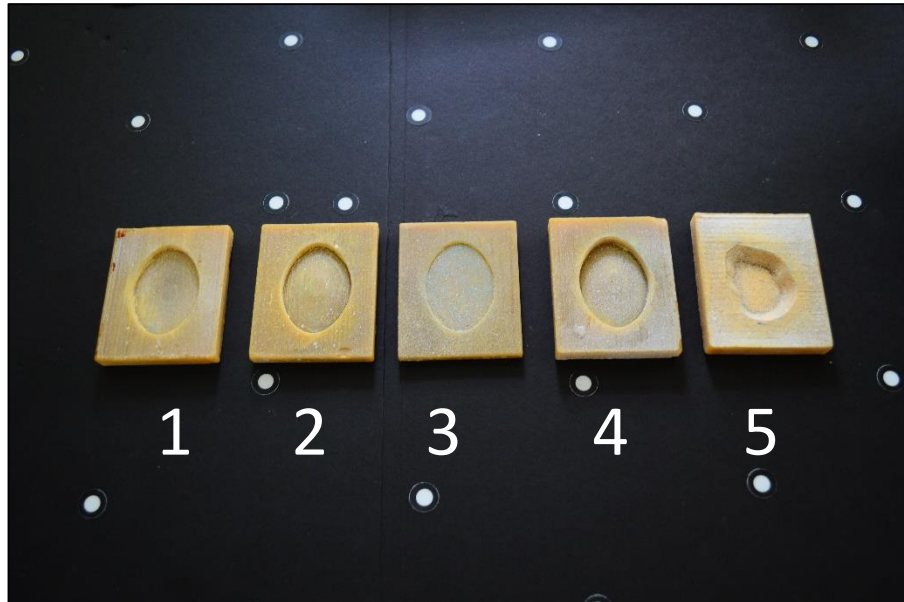


Figure 12: Schematic flow diagram of methodology for the project.

### 3.2 LASER SCANNING

There are 5 ulcer models that is being scanned in this project and shown in Figure 13. They are of different attributes and descriptors.



*Figure 13: 5 ulcer models that are being used for testing.*

Before the laser scanning process can be started, the laser scanner should be set up and connected to the computer. The setup of the laser scanner can be seen in the figure below.



*Figure 14: Setup of the Laser scanning process.*

Then the laser is being calibrated using the calibration plate provided by the laser scanner company. The last preparation steps is to configure the laser power and shutter speed. The laser power and shutter are adjusted so that they can provided best reading or data during the scanning process.



Figure 15: The calibration plate and calibration process.

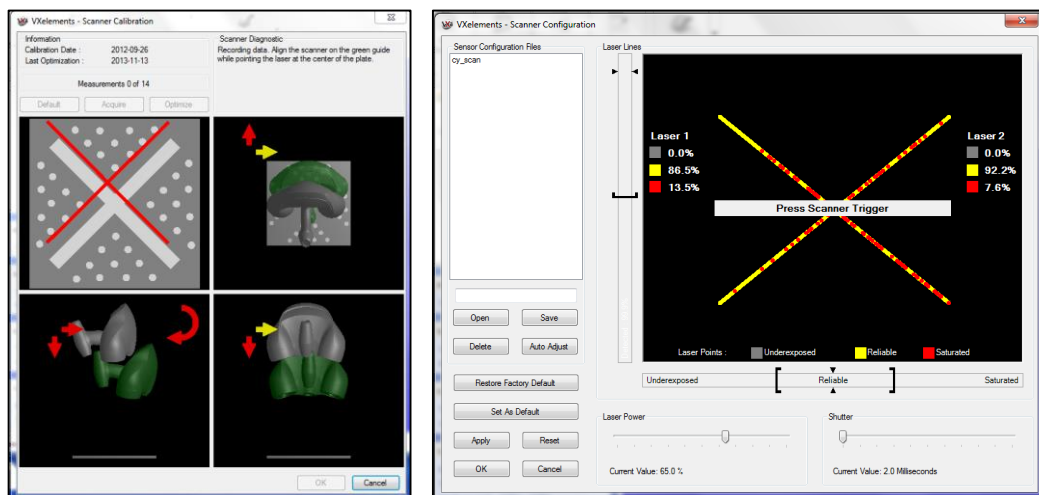


Figure 16: The calibration windows (left) and the configuration windows (right).

Scanning are being carried out with different resolution so that the optimum resolution for scanning the ulcer model can be determined. The resolution that is being tested are 1.95mm, 0.98mm, 0.5mm and 0.2mm. Determining an optimum resolution for scanning is very crucial as high resolution scanning will consume high memory usage of the



### **3.3 MATLAB ALGORITHM**

Overall, the methodology for MATLAB algorithm is as below:

- Importing the binary stl file
- Reduce the duplicate vertices and facets.
- Detecting the neighbor for each vertices and facet.
- Detecting the curvature of the scanned model,  $K_m$ .
- Segmentation of the ulcer area by specifying suitable  $K_m$  value.
- Quantitative analysis of the ulcer for volume and area using convex hull approach.

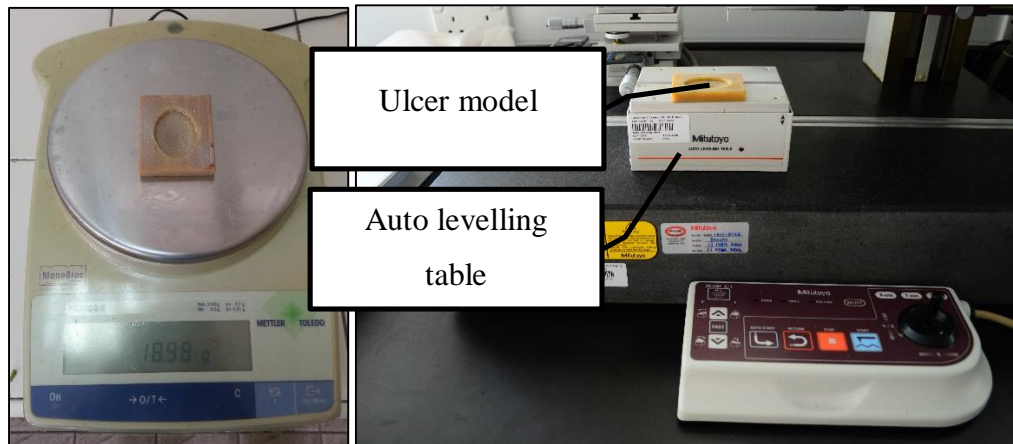
The main and vital MATLAB code for the above mentioned steps is attached in the appendix section of this report.

### **3.4 INVASIVE METHOD**

#### **3.4.1 MEASURING VOLUME**

To measure the volume by invasive method, the equipment and apparatus needed are an electronic balance, auto leveling table, water level and syringe.

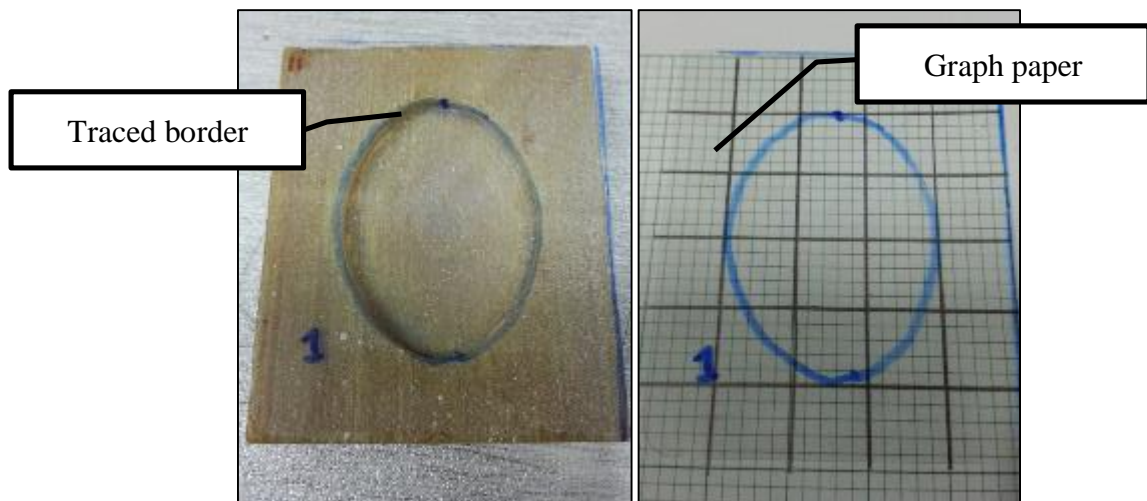
First of all, the model of skin ulcer should be placed on an electronic balance and the electronic balance should be place on top of the auto leveling table. The water level is place on the model and the auto leveling table is adjust to that the water level shows flat reading. This steps is to ensure that the flatness of the model is maintained. Then, the initial mass of the skin ulcer is then measured from the electronic balance. Water is filled carefully into the ulcer cavity by using a syringe. The water is filled until the whole cavity is full. Parallax error should be avoided in this steps of experiment as there might be overfilled or less if the error occurs. The electronic balance and the auto leveling table is shown in Figure 19.



*Figure 19: The electronic weighing balance (left) and the auto levelling table (right).*

### 3.4.2 MEASURING AREA

The current method of measuring area is to place a transparent acetate sheet onto the ulcer model and to trace the perimeter of the ulcer cavity on the model. The tracing is then placed onto graph paper and the number of squares counted. The methodology of measuring the area of the ulcer model are as shown in Figure 20.



*Figure 20: The methodology of measuring the area of the ulcer model.*

### 3.5 COMPARING THE RESULT

All the model are being scanned for 3 times. The invasive method experiment are also being carried out 3 times for each of the ulcer model. The percentage error of the scanning result is calculated compared to the result from invasive method using the following equation.

$$\% \text{ error} = \frac{|\text{experimental value} - \text{control value}|}{\text{control value}} \times 100 \text{ -----(8)}$$

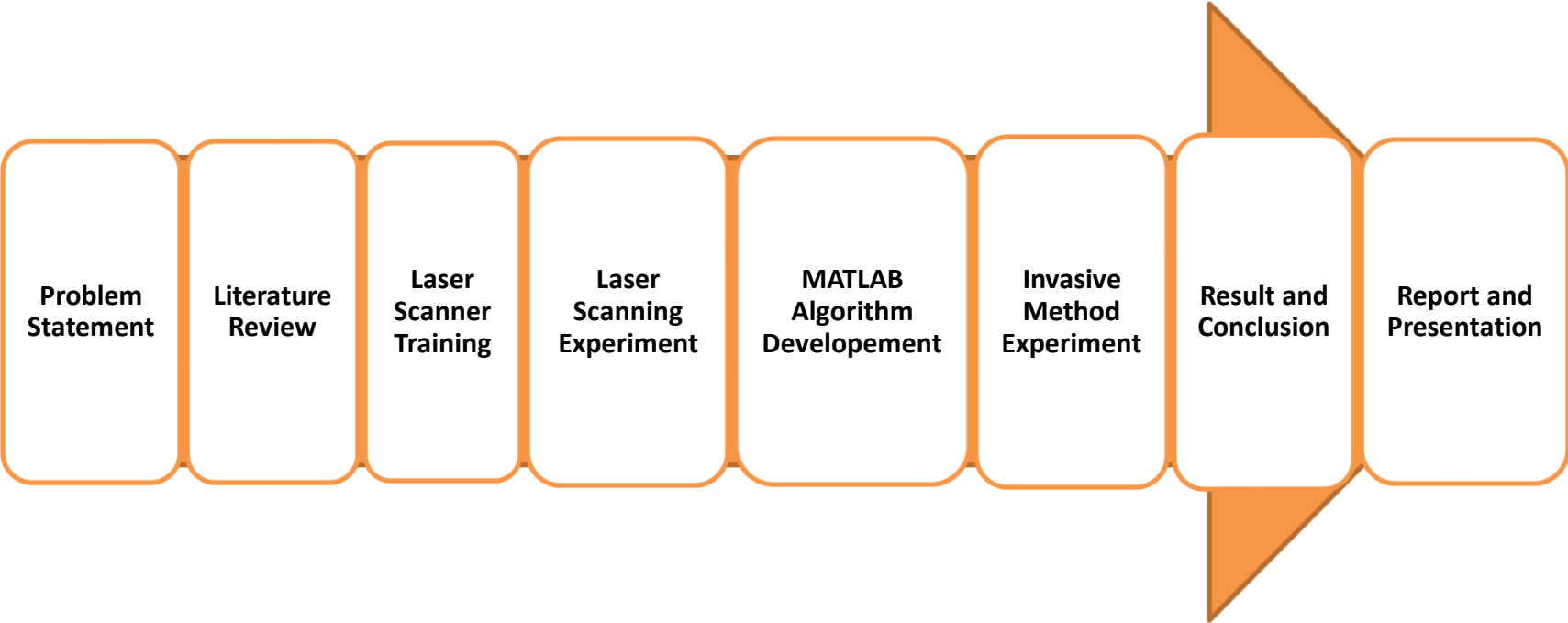
To justify the precision, standard deviation of the scanning result is also calculated with (7). The standard deviation is being calculated in percentage form. This is done by dividing the standard deviation by the average value of each attributes and multiply by 100.

$$\sigma = \sqrt{\left(\frac{\sum_{i=1}^N (X_i - \bar{X})^2}{N}\right)} \text{ -----(9)}$$



**3.6 KEY MILESTONES**

The key milestones of this project are as shown in the flowchart in Figure 21.



*Figure 21: The key milestone for Final Year Project.*

### 3.7 STUDY PLAN (GANTT-CHART)

Training activities	Week Number																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 /1	16/ 2	17/ 3	18/ 4	19/ 5	20/ 6	21/ 7	22 /8	23/ 9	24/ 10	25/ 11	26/ 12	27/ 13	28/ 14	
Problem Statement																													
Literature Review																													
Laser Scanning Training																													
Laser Scanning Experiment																													
MATLAB Algorithm Development																													
• Segmentation																													
• Quantitative analysis																													
Invasive Method Experiment																													
Result and Conclusion																													
Report & Presentation																													

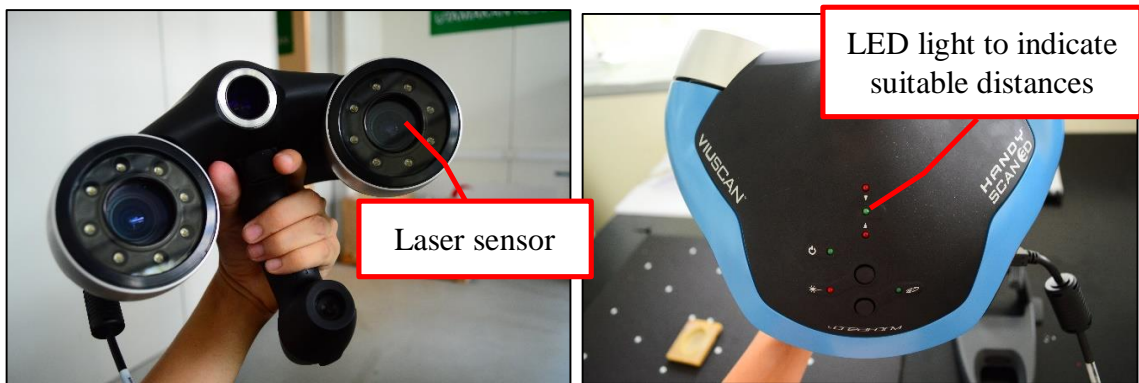
Table 4: Gantt-chart for FYPI and FYPII.

Legend:

	FYP I
	FYP II

### 3.8 EQUIPMENT AND APPARATUS

The equipment that is being used in this project is the portable laser scanner by CREAFORM. The model of the laser scanner is VIUscan as shown in Figure 22. This include the calibration plate, the markers and also the software, VXelement, provided by the supplier.



*Figure 22: VIUscan laser scanner by CREAFORM.*

Next we need the ulcer model as the experiment target for this project. The apparatus needed is the electronic balance, water level and auto level table. Other than that, we need acetate sheet, and graph paper.

Since we are using MATLAB as the computational tool, we need a laptop with MATLAB installed.

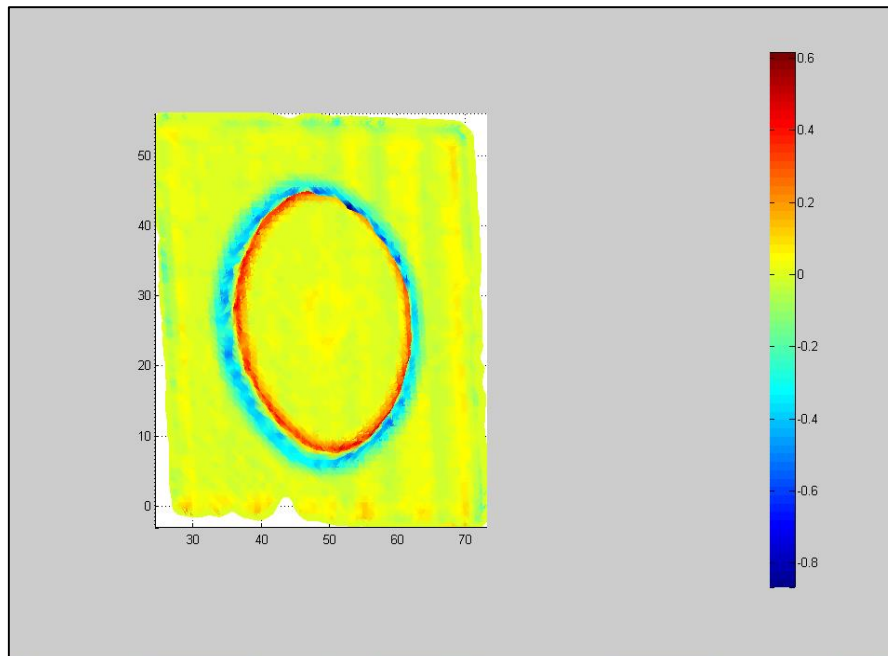
## CHAPTER 4

### RESULT AND DISCUSSION

#### 4.1 RESULT

##### 4.1.1 ULCER BORDER DETECTION

The result shows that the algorithm developed are capable of detecting the border of the ulcer based on the mean curvature of the surface,  $K_m$ . However, the condition of the region growing must be changed based on different mean curvature value. Example of curvature values for model 1, is as shown in Figure 23 while the border detected and the segmented region is being shown in Figure 24. In Figure 23, the blue colour represent the surface which has negative value of mean curvature (crest), the yellow colour represent the surface which has approximately zero mean curvature value (flat) and the red colour represent the surface which has positive curvature value (valley). In Figure 24, the blue colour represent the border of the ulcer that has been detected while the green colour is the segmented ulcer after performing region growing.



*Figure 23: Mean curvature value of the surface of model 1.*

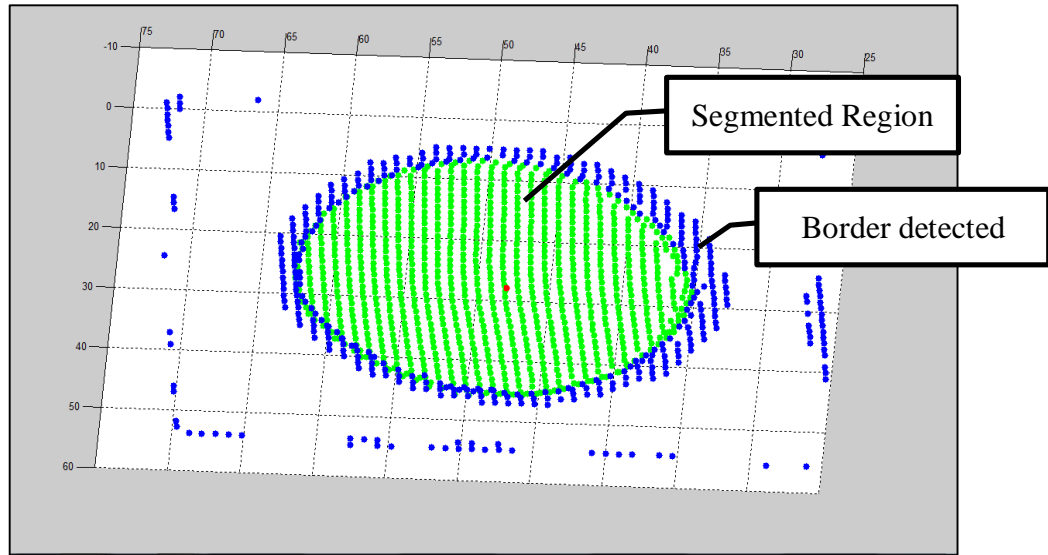


Figure 24: Border detected and the segmented region of the ulcer.

#### 4.1.2 RESULT OF INVASIVE METHOD AND NON-INVASIVE METHOD

The result for both non-invasive and invasive method of assessing the quantitative measurement of the skin ulcer model are as shown in Table 5, Table 6 and Table 7.

	Volume, mm <sup>3</sup>			
	Scan 1	Scan 2	Scan 3	Average
Model 1	2705.00	2713.30	2610.20	2676.17
Model 2	2101.30	2144.70	2133.90	2126.63
Model 3	759.70	770.70	775.20	768.53
Model 4	3717.00	4031.50	3865.60	3871.37
Model 5	2217.60	2398.00	2423.70	2346.43

Table 5: The volume measurement for non-invasive method.

	Area, mm <sup>2</sup>			
	Scan 1	Scan 2	Scan 3	Average
Model 1	807.57	886.38	883.95	859.306
Model 2	799.34	888.64	888.25	858.749
Model 3	819.41	906.97	906.82	877.740
Model 4	821.60	894.96	888.54	868.371
Model 5	617.65	722.31	727.15	689.041

Table 6: The area measurement for non-invasive method.

	Volume, mm <sup>3</sup>				Area, mm <sup>2</sup>
	<i>Experiment 1</i>	<i>Experiment 2</i>	<i>Experiment 3</i>	<i>Average</i>	
Model 1	2505.05	3000.00	3131.31	2878.79	828
Model 2	1828.28	2080.81	1989.90	1966.33	808
Model 3	686.87	808.08	959.60	818.18	848
Model 4	3424.24	3707.07	3525.25	3552.19	840
Model 5	2484.85	2676.77	2444.44	2535.35	716

Table 7: The volume and area measurement for invasive method.

The result is being plotted into graph as shown for the better viewing purpose.

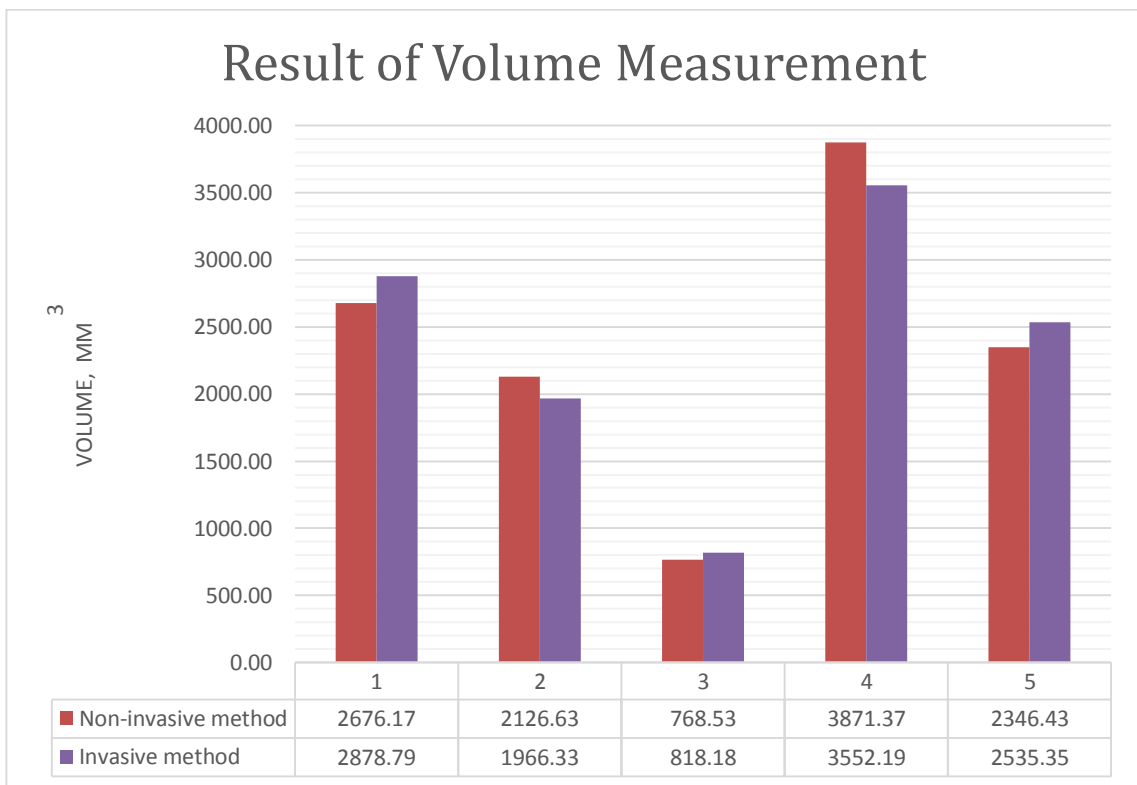


Figure 25: The average volume measurement.

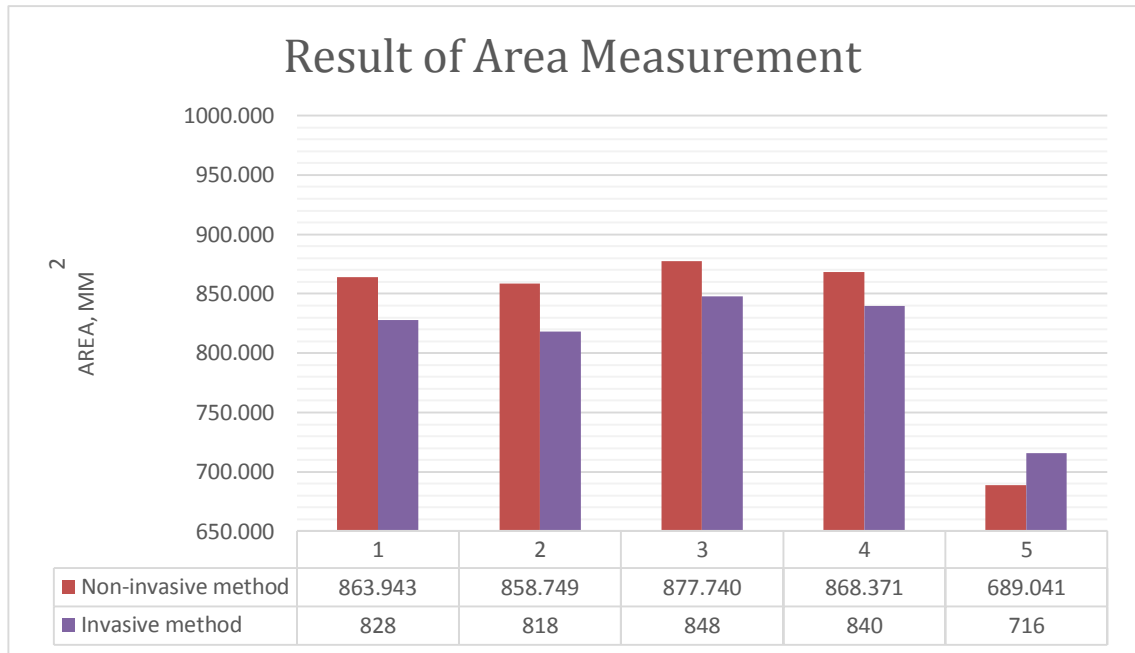


Figure 26: The average area measurement using.

## 4.2 DISCUSSION

### 4.2.1 RESULT DISCUSSION

From the results obtained, the percentage error and the standard deviation for the scanning can be calculated. Figure 27 and Figure 28 show the percentage error and the standard deviation respectively.

From the percentage error calculated, we can see that the method used in this work has low percentage error, which is less than 10%. The insensitivity of invasive method may contribute to the percentage error. For example, the invasive method of volume measurement has only  $10\text{mm}^3$  sensitivity while the non-invasive method used has sensitivity up to  $1\text{mm}^3$ . The same problem occurs to the area measurement as well where the sensitivity of invasive method is  $1\text{mm}^2$  and sensitivity of non-invasive method is  $0.01\text{mm}^2$ . Other than that, we can also observe that model 2 and model 4 have relatively high percentage error on volume measurement. This is caused by the convex hull computation method used. Model 2 and model 4 are skin ulcer which have elevated based. The convex hull computation method will cause over estimation as shown in Figure 29.



Figure 27: Percentage error for volume and area measurement from scanning.

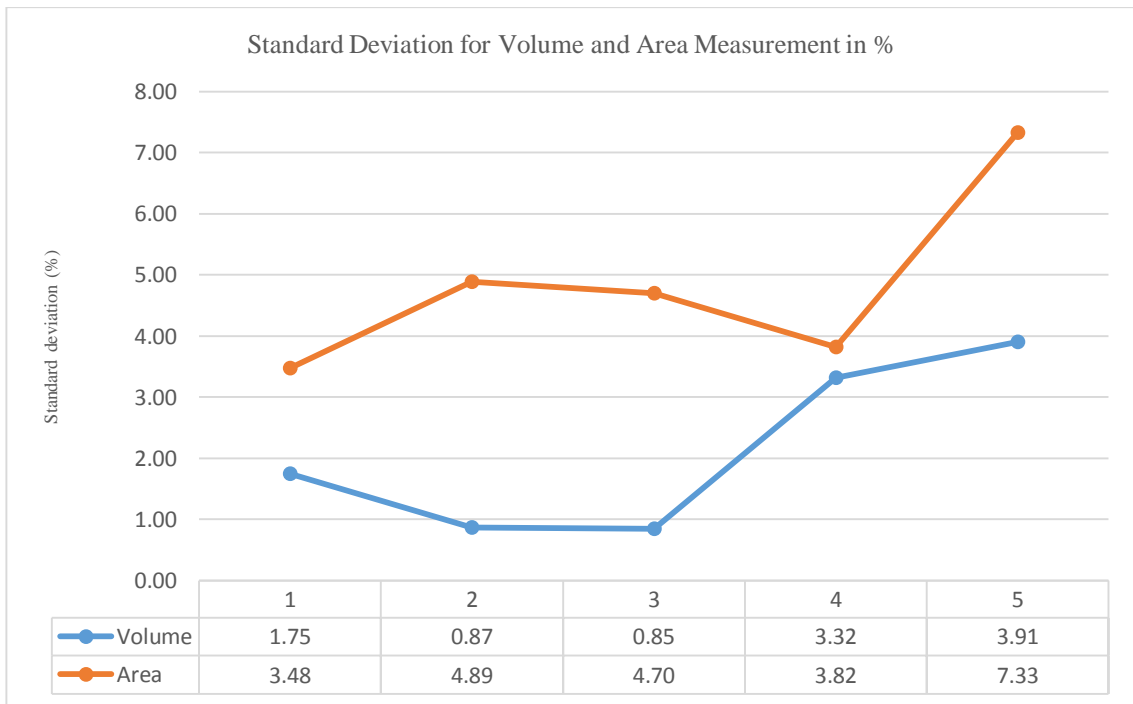


Figure 28: Standard deviation for volume and area measurement from scanning.



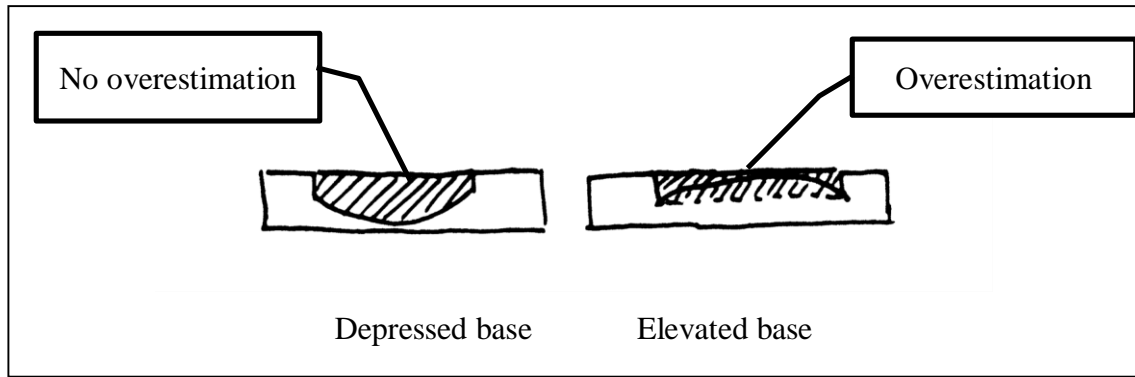


Figure 29: Comparison of convex hull computation between depressed base and elevated base.

For the standard deviation calculation, we can see that the percentage of standard deviation for both volume and area are small, which is less than 4% and less than 8% respectively. However, model 5 has the high standard deviation of all the model scanned. This may be due to the irregular border shape of the ulcer model.

#### 4.2.2 PROJECT DISCUSSION

The progress of the FYP is as planned in the Gantt-chart. All of the work are done as mentioned in the Gantt-chart.

Literature review for the project is being carried out continuously with respect to the progress of the project. Information and knowledge about the project are being studied to solve the problems encountered during the project. For example, there are a new work [22], which utilize the mobile phone camera to carry out the 3D reconstruction. This work can be greatly helpful in giving direction to the future work of this project.

Besides the main activity of FYP, I have also attended two trainings throughout the FYP period. The trainings attended are ENDNOTE training and GeoMagic Studio training. The purpose of ENDNOTE training is to simplify the process of literature review where the source of the references can be organized in systematically by using ENDNOTE software. Meanwhile, the objective of Geomagic Studio training is to aids the laser scanner experiment, where the GeoMagic Studio is a software that can view, handle and process the point clouds scanned.

Other than that, I have also given my assistance and support to the other ETP group and also Post graduate students in terms of handling the laser scanner and post processing method of the point cloud for their projects. This includes to give them some idea about how to use the VXelement software like to adjust the viewpoint, adjust the resolution and also adjust the zooming during the scanning session.

## **CHAPTER 5**

### **CONCLUSION AND FUTURE WORK**

#### **5.1 CONCLUSION**

In conclusion, the non-invasive method of skin ulcer assessment overcome most of the problem possess by invasive method. However, most of the non-invasive related work developed in the field of wound assessment requires tedious post processing and some lack of repeatability. In this work, the healing progress of the skin ulcer is determined by the volume and the area. The border of the skin ulcer is determined and segmented by computing the mean curvature of the surface. The volume and area of the segmented region is then calculated by using convex hull computation method. The goal is to introduce a new non-invasive technique to assess the healing status of chronic wounds in an accurate, simpler and more precise way.

#### **5.2 FUTURE WORK**

For future work, concave hull computation for measuring the volume of ulcer which has elevated base can be developed to overcome the weakness of convex hull method. The measurement of area can also be improvised by projecting the border to a plane before the convex hull algorithm is being applied.

Other than that, based on the work [22], a mobile application for measuring the skin ulcer size can be developed to further simplify the assessing of quantitative measurement of the skin ulcer and thus monitoring the healing progress of skin ulcer can be carried out even by the patient themselves.

## CHAPTER 6

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## CHAPTER 7

### APPENDICES

#### 7.1 MATLAB ALGORITHM – Importing the Binary STL file

```
function [v, f, n, c, stltitle] = sthread(filename, verbose)
% This function reads an STL file in binary format into vertex and face
% matrices v and f.
%
% USAGE: [v, f, n, c, stltitle] = sthread(filename, verbose);
%
% verbose is an optional logical argument for displaying some loading
% information (default is false).
%
% v contains the vertices for all triangles [3*n x 3].
% f contains the vertex lists defining each triangle face [n x 3].
% n contains the normals for each triangle face [n x 3].
% c is optional and contains color rgb data in 5 bits [n x 3].
% stltitle contains the title of the specified stl file [1 x 80].
%
% To see plot the 3D surface use:
% patch('Faces',f,'Vertices',v,'FaceVertexCData',c);
% or
% plot3(v(:,1),v(:,2),v(:,3),'.');
%
% Duplicate vertices can be removed using:
% [v, f]=patchslim(v, f);
%
% For more information see:
% http://www.esmonde-white.com/home/diversions/matlab-program-for-loading-stl-
files
%
% Based on code originally written by:
% Doron Harlev
% and combined with some code by:
% Eric C. Johnson, 11-Dec-2008
% Copyright 1999-2008 The MathWorks, Inc.
%
% Re-written and optimized by Francis Esmonde-White, May 2010.

use_color=(nargout>=4);

fid=fopen(filename, 'r'); %Open the file, assumes STL Binary format.
if fid == -1
    error('File could not be opened, check name or path.')
end
```

```

if ~exist('verbose','var')
    verbose = false;
end

ftitle=fread(fid,80,'uchar=>schar'); % Read file title
numFaces=fread(fid,1,'int32'); % Read number of Faces

T = fread(fid,inf,'uint8=>uint8'); % read the remaining values
fclose(fid);

stltitle = char(ftitle);

if verbose
    fprintf('\nTitle: %s\n', stltitle);
    fprintf('Number of Faces: %d\n', numFaces);
    disp('Please wait...');
end

% Each facet is 50 bytes
% - Three single precision values specifying the face normal vector
% - Three single precision values specifying the first vertex (XYZ)
% - Three single precision values specifying the second vertex (XYZ)
% - Three single precision values specifying the third vertex (XYZ)
% - Two color bytes (possibly zeroed)

% 3 dimensions x 4 bytes x 4 vertices = 48 bytes for triangle vertices
% 2 bytes = color (if color is specified)

trilist = 1:48;

ind = reshape(repmat(50*(0:(numFaces-
1)),[48,1]),[1,48*numFaces])+repmat(trilist,[1,numFaces]);
Tri = reshape(typecast(T(ind),'single'),[3,4,numFaces]);

n=squeeze(Tri(:,1,:));
n=double(n);

v=Tri(:,2:4,:);
v = reshape(v,[3,3*numFaces]);
v = double(v);

[vnew, indexm, indexn] = unique(v, 'rows');

f = reshape(1:3*numFaces,[3,numFaces]);

fnew = indexn(f);

```



```

if use_color
    c0 = typecast(T(49:50),'uint16');
    if (bitget(c0(1),16)==1)
        trilist = 49:50;
        ind = reshape(repmat(50*(0:(numFaces-
1)),[2,1]),[1,2*numFaces])+repmat(trilist,[1,numFaces]);
        c0 = reshape(typecast(T(ind),'uint16'),[1,numFaces]);

        r=bitshift(bitand(2^16-1, c0),-10);
        g=bitshift(bitand(2^11-1, c0),-5);
        b=bitand(2^6-1, c0);
        c=[r; g; b]';
    else
        c = zeros(numFaces,3);
    end
end

if verbose
    disp('Done!');
end

```

## 7.2 MATLAB ALGORITHM – Reducing the Duplicate Vertices and Facets

```
function [vnew, fnew]=patchslim(v, f)
% PATCHSLIM removes duplicate vertices in surface meshes.
%
% This function finds and removes duplicate vertices.
%
% USAGE: [v, f]=patchslim(v, f)
%
% Where v is the vertex list and f is the face list specifying vertex
% connectivity.
%
% v contains the vertices for all triangles [3*n x 3].
% f contains the vertex lists defining each triangle face [n x 3].
%
% This will reduce the size of typical v matrix by about a factor of 6.
%
% For more information see:
% http://www.esmonde-white.com/home/diversions/matlab-program-for-loading-stl-
files
%
% Francis Esmonde-White, May 2010

if ~exist('v','var')
    error('The vertex list (v) must be specified.');
```

```
end
if ~exist('f','var')
    error('The vertex connectivity of the triangle faces (f) must be specified.');
```

```
end

[vnew, indexm, indexn] = unique(v, 'rows');
fnew = indexn(f);
```

### 7.3 MATLAB ALGORITHM – Detecting the neighbor of each vertices and facets

```
function [neighbourfaces] = Findneighbourfaces (v,f)
```

```
[N,~] = size(v);
```

```
[M,~] = size(f);
```

```
neighbourfaces = cell(1,M);
```

```
for i = 1:N
```

```
    disp(i);
```

```
    neighbourtmpf = [];
```

```
    idx = find(f(:,1)==i);
```

```
    idx2 = find(f(:,2)==i);
```

```
    idx3 = find(f(:,3)==i);
```

```
    if(~isempty(idx))
```

```
        neighbourtmpf = [neighbourtmpf idx'];
```

```
    end
```

```
    if(~isempty(idx2))
```

```
        neighbourtmpf = [neighbourtmpf idx2'];
```

```
    end
```

```
    if(~isempty(idx3))
```

```
        neighbourtmpf = [neighbourtmpf idx3'];
```

```
    end
```

```
    neighbourfaces{1,i} = unique(neighbourtmpf); %
```

```
    strread(num2str(unique(neighbourtmp)), '%s');
```

```
end
```

## 7.4 MATLAB ALGORITHM – Calculating the curvature value of the surface

```
function
[Km,Kg,Vmax,Vmin,K1,K2,Kmapprox,Kgapprox]=ComputeCurvature(Vx,Vy,Vz,a,b,c)
% ,Kmax,Kmin,Vmax,Vmin

[nbpt]=length(a);

A=[(a).^2 2.*a.*b (b).^2];

At=A';

AtAm1=pinv(At*A);

B=AtAm1*At*c;

Km=B(1)+B(3);
Kg=4*(B(1)*B(3)-(B(2)^2));

CurvatureTensor=[B(1) B(2);
                  B(2) B(3)];

[EigVect,Lambda]=eig(CurvatureTensor);

[valmax,indmaxc]=max(max(Lambda));
[~,indmaxl]=max(Lambda(:,indmaxc));

[valmin,indminc]=min(min(Lambda));
[~,indminl]=min(Lambda(:,indminc));

Vmax=EigVect(1,indmaxc)*Vx+EigVect(2,indmaxc)*Vy;
Vmin=EigVect(1,indminc)*Vx+EigVect(2,indminc)*Vy;

% Km=k1+k2
% K1=km-k2

% Kg=k1*k2
% Kg=(km-k2)*k2=km*k2-k2^2

% -K2^2+km*k2-kg=0

D=Km^2-4*(-1)*(Kg);

if(D>=0)
    K2_1=(-Km-sqrt(D))/(2*(-1));
    K2_2=(-Km+sqrt(D))/(2*(-1));
```

```

K1_1=Km-K2_1;
K1_2=Km-K2_2;

if(K1_1>K2_1)
    K1=K1_1;
    K2=K2_1;
else
    K1=K1_2;
    K2=K2_2;
end
else
K2_1=abs((-Km-1i*sqrt(abs(D)))/(2*(-1)));
K2_2=abs((-Km+1i*sqrt(abs(D)))/(2*(-1)));

K1_1=Km-K2_1;
K1_2=Km-K2_2;
if(K1_1>K2_1)
    K1=K1_1;
    K2=K2_1;
else
    K1=K1_2;
    K2=K2_2;
end
% disp('Error Principal Curvature values!!!!');
end
Kmapprox=(K1+K2);
Kgapprox=4*K1*K2;
% disp('fin');

```