International Journal of Medical, Medicine and Health Sciences
ISSN: 2517-9969
Vol:5, No:10, 2011

Analytical Studies on Volume Determination of Leg Ulcer using Structured Light and Laser Triangulation Data Acquisition Techniques

M. Abdul-Rani, K. K. Chong, A. F. M. Hani, Y. B. Yap and A. Jamil

***Abstract*—**Imaging is defined as the process of obtaining geometric images either two dimensional or three dimensional by scanning or digitizing the existing objects or products. In this research, it applied to retrieve 3D information of the human skin surface in medical application. This research focuses on analyzing and determining volume of leg ulcers using imaging devices. Volume determination is one of the important criteria in clinical assessment of leg ulcer. The volume and size of the leg ulcer wound will give the indication on responding to treatment whether healing or worsening. Different imaging techniques are expected to give different result (and accuracies) in generating data and images. Midpoint projection algorithm was used to reconstruct the cavity to solid model and compute the volume. Misinterpretation of the results can affect the treatment efficacy. The objectives of this paper is to compare the accuracy between two 3D data acquisition method, which is laser triangulation and structured light methods, It was shown that using models with known volume, that structured-light-based 3D technique produces better accuracy compared with laser triangulation data acquisition method for leg ulcer volume determination.

***Keywords*—**Imaging, Laser Triangulation, Structured Light, Volume Determination.

I. Introduction

ULCERS refer to the discontinuity of skin exhibiting complete loss of the epidermis which is not short lived. The duration of the ulcer could last from a few weeks to even few years. Patients suffering from such chronic skin have faced a huge loss in quality of life. The patient not only has to endure pain but also time consuming outpatient treatment and considerable cost of transportation.

Currently, dermatologists do not have any quantitative tool to assess the severity and the healing rate for the leg ulcer [1]. The clinical evaluation of the leg ulcer depended heavily on the skills of the dermatologist with the help of predetermined assessment criteria such as the Leg Ulcer Measurement Tools [2], which is mainly qualitative. The examination process is very time consuming. With the huge number of patients suffering from this disease, a quantitative method needs to be researched and developed. The main issues are reliability, repeatability and accuracy of the current ulcer assessment and reduction in time spent on ulcer examination. Normally, the dermatologists will evaluate leg ulcers based on four main criteria, which are volume, area, percentage of the granulation tissue and percentage of the necrotic tissue of the wound. The first indicator of wound healing is changes in wound volume followed by a gradual decrease in perimeter and area [3].

Every evaluation has therapeutic consequences which differ depending on the treating dermatologist [4]. It is generally accepted that good clinical assessment normally leads to good treatment. There exists more than 200 possible dressing material and treatment in market. The visual observation method might not result in the best treatment for the patient due to the subjective nature of the assessment. Different levels of ulcer severity require different dressing and treatment remedies which will best promote the healing process of the ulcer. In contrast, unsuitable dressing and remedies may not worsen the condition.

Hence, efficacy on the leg ulcer assessment is very important in determining the treatment approach and the healing process.

One application of the uses of imaging device is to retrieve the three dimensional geometrical shape of the object surface in digital form which could be stored in any computer system which is useful for treating dermatologist. Data accuracy is dependent on the type of data acquisition technique such as laser triangulation method or structured light method. Time taken to complete the scanning of patient is also an important factor to ensure reliability and accuracy of the data. Due to human nature, it is impossible for a human to stay still for a long period. Pain, discomfort, and even breathing can cause slight movement which affect the reliable and accuracy of the scanned data.

The research is focused on comparing the accuracy of laser triangulation data acquisition technique and structured light data acquisition technique. The pros and cons of these two techniques will be ascertained.

A. M. Abdul-Rani is with the Mechanical Engineering Department, Universiti Teknologi PETRONAS, Bandar Seri Tronoh, Perak Darul Ridzuan, Malaysia (phone: +605-368-7001; fax: +605-368-6461; e-mail: majdi@petronas.com.my).

K. K. Chong is with the Mechanical Engineering Department, Universiti Teknologi PETRONAS, Bandar Seri Tronoh, Perak Darul Ridzuan, Malaysia (e-mail: evan_ckk@hotmail.com).

A. F. M. Hani is with the Electrical & Electronics Engineering Department, Universiti Teknologi PETRONAS, Bandar Seri Tronoh, Perak Darul Ridzuan, Malaysia (e-mail: fadzmo@petronas.com.my).

F. B. Yap, is with the Department of Dermatology, Hospital Kuala Lumpur, Kuala Lumpur, Malaysia (e-mail: woodzlamp@yahoo.com)

A. Jamil is with the Department of Dermatology, Hospital Kuala Lumpur, Kuala Lumpur, Malaysia (e-mail: adda_jamil@yahoo.com).

II. Background

Imaging devices are widely applied in many industries. Basic imaging devices that are used in the medical field are Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and also 3D scanner to enable a more efficient process of diagnosis. Both CT and MRI use transmissive approach for internal part visualization. CT reconstructs images by projecting an X-ray beam through an object from many angles and measuring the amount of radiation that passes through it whereas MRI uses magnetic fields and radio wave to visualize detail internal structure of human body. 3D scanner uses the reflective approach instead of transmissive approach. Fig. 1 shows the classification of imaging devices. Laser and optical scanners are used in this research. Laser scanner uses the laser triangulation data acquisition technique whereas optical scanner uses structured light data acquisition technique. Laser Triangulation is the most common technique used in the 3D scanner. It uses straightforward geometric triangulation to determine the surface coordinates of an object. Structured light method has continuously evolved over the years and is widely used especially in medical application. It combine the triangulation technique and fringe pattern technique in data acquisition. Analytical studies are conducted to understand the working principle of laser triangulation method and structured light method.

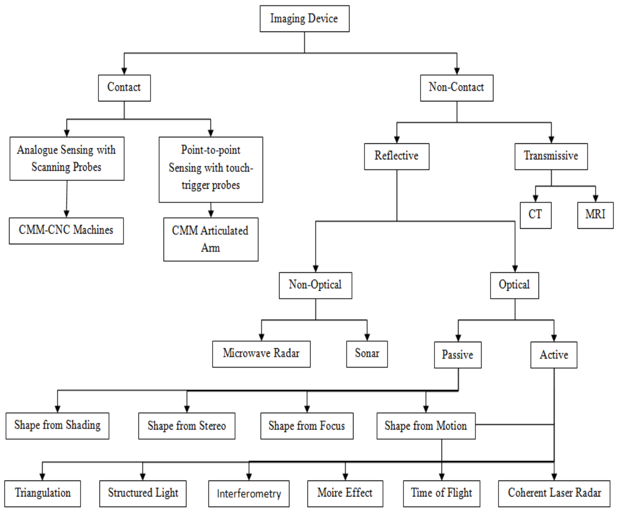


Fig. 1 Classification of imaging technique

There are two main techniques for measuring the volume of the wound cavity [5]. The first technique is to fill the wound cavity with saline. The volume of saline dispensed from the syringe is equivalent to the ulcer volume [6]. However, the wound might absorb the saline and the shape of plastic covers might not be the same as the original healthy skin which will affect the accuracy of the exact ulcer volume. Fig. 2 shows the proper procedure for dispensing the saline to the wound cavity. The second technique used is to fill the cavity with alginate or silicon based paste and to weigh the amount of material used. These techniques are invasive and might bring the infection to the patients and normally used for research purposes.

Fig. 2 Dispensing the saline to the wound cavity [7]

A lot of research on the wound assessment has been carried out to develop wound assessment tools that are low cost and easily operated by dermatologists or nurses [8]. Some prototypes based on structured light technique [9-10] or photogrammetry [11-12] were tested to obtain the spatial measurement, but were not adapted to the clinical practice.

Extensive work has been carried out to analyze the MAVIS (Measurement of Area and Volume Instrument system) method in comparison to the traditional method [13]. This method is based on the structured light technique and the equipment weighed more than 100kg. MAVIS results are better than the traditional methods in repeatability of volume, area and depth measurement. Volume measurements with a large area/volume ratio are less precise than those with a smaller one. Nevertheless, MAVIS has its own drawback. Due to the optical principle of this instrument, it is incapable of measuring wounds that are undermined. Fig. 3 shows the schematic drawing of ulcer with undermining. However, it is now obsolete and replaced by the MAVIS II that uses only a reflex digital camera equipped with special dual lens optics to record two half images from slightly different viewpoint [7].

Fig. 3 Schematic drawing of ulcer with undermining [6].

Derma is another integrated tool which allows measurement and assessment of time evolution of chronic wounds [14]. It provides a single and uniform interface to manage data, 3D scanning of the lesional region, and to perform different kinds of measurements and comparisons. The healthy skin surface was computed by interpolating a surface passing in the proximity of the wound border. The healthy skin nearby is taken into consideration while computing the approximate healthy skin for ulcer. However, it is not suitable to measure the leg ulcer due to the curvature and irregular shape of the leg.

Midpoint projection algorithm was proposed in computing the estimated healthy skin surface for the volume computation [15]. It is suitable for the ulcer with centre point inside the wound.

III. Methodology

This research is focused on volume determination using models with known volume which shown in Fig. 4.

Ulcer can appear in various shapes with different sizes. Four attributes were introduced to represent various types of the ulcer shape which are shown in Table 1.

In the validation stage, 17 models with the combination of different attributes were built to validate the data acquisition technique and the volume computation algorithm. Due to the nature of light that cannot pass through the skin, undermined edge is not covered in this research. The cavity of the models will be measured using conventional and non-contact 3D imaging methods.

A. Conventional Method

In conventional method of volume measurement, mould material is used to measure the cavity volume of a model. Initially, mould material is applied to the cavity of models. After filling the cavity with the amount required, mould material will be taken out and put into a beaker filled with water. The water that is displaced from the beaker represents the volume of the model's cavity.

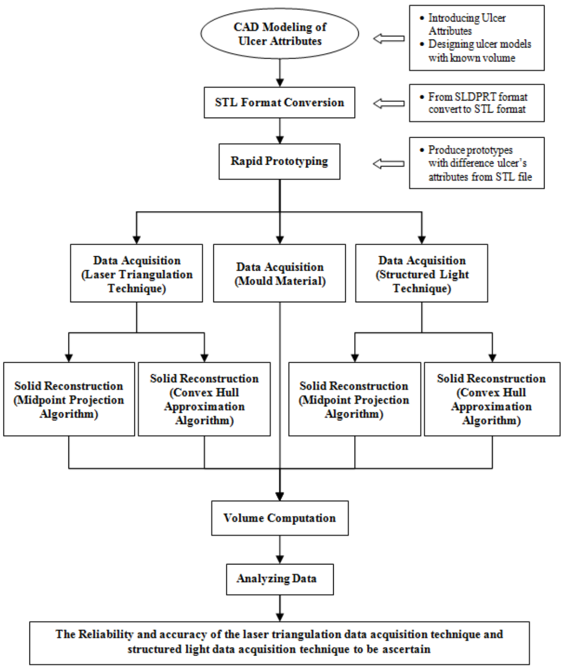


Fig. 4 Process flow of volume determination using models with known volume

B. Noncontact 3D Imaging Method

Two 3D scanners, which are Konica laser scanner (laser triangulation data acquisition technique) and Primos optical scanner (structured light data acquisition technique) are used to capture the 3D images of the models. Before measuring the volume of the ulcer cavity, some of the point processing work must be done. The model cavity will be cropped out in order to measure the volume cavity.

TABLE I
Four Attributes of Wound

Attributes	Descriptor	Schematic
Boundary	Regular	
	Irregular	
Edge	Sloped	
	Punched Out	
	Undermined	
Base	Elevated	
	Homogenous	
	Depressed	
Depth	Unit (mm)	x mm

Then, midpoint of the cropped model must be figured out prior to volume computation. Due to the triangular characteristic of the nature CAD file, the cropped models show irregular boundary and zip zap shape. Fit boundary command was just to fit the boundary fitting. Eventually, the processed data will be sent for image processing to measure its cavity volume using midpoint projection method.

By comparing the results obtained from 3D imaging techniques, the reliability and the accuracy between laser triangulation and structured light techniques could be ascertained.

IV. Result and Discusssion

Seventeen models with known volume were used to compare the accuracy of data acquisition using midpoint projection algorithm. The coefficient of determination (R^2) is statistical measure of how well the regression line approximates the ideal line and the equation is shown in (1). An R^2 value of 1.0 show the regression line is perfectly fits the ideal data.

International Journal of Medical, Medicine and Health Sciences
ISSN: 2517-9969
Vol:5, No:10, 2011

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left[(x_i)_{measured} - (x)_{reference}\right]^2}{\sum_{i=1}^{N}\left[(x_i)_{measured} - \bar{x}\right]^2} \quad (1)$$

From the equation, $(x_i)_{measured}$ is representing the volume measured for each model, $(x)_{reference}$ is the reference volume for each model and $\bar{x}$ representing mean value for the measured volume.

Based on (1), volume measurement using mould material shows highest value of R^2 which at 0.998818 whereas Primos optical scanner and Konica laser scanner shows the R^2 value at 0.995671 and 0.994050 respectively. R^2 is obtained to help in prediction of the experimental results when the reference volume is given. It shows that volume computation using mould material gives the best fitting toward reference volumes and followed by Primos optical scanner and Konica laser scanner.

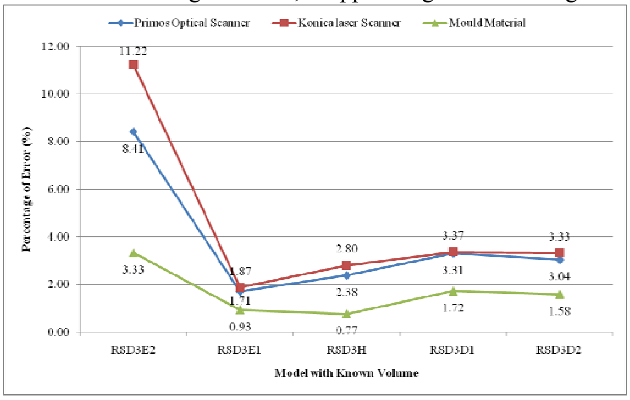
TABLE II
PERCENTAGE OF ERROR FOR 17 MODELS WITH KNOWN VOLUME USING MIDPOINT PROJECTION ALGORITHM

Model	Reference Value (mm^3)	Primos Optical Scanner		Konica Laser Scanner		Mould Material	
		Mean Value (mm^3)	Percentage of Error (%)	Mean Value (mm^3)	Percentage of Error (%)	Mean Value (mm^3)	Percentage of Error (%)
RSD1H	397	408	2.77	423	6.55	366	7.81
RSD3E2	1141	1237	8.41	1269	11.22	1179	3.33
RSD3E1	1284	1306	1.71	1308	1.87	1296	0.93
RSD3H	1428	1462	2.38	1468	2.80	1439	0.77
RSD3D1	1571	1623	3.31	1624	3.37	1598	1.72
RSD3D2	1713	1765	3.04	1770	3.33	1686	1.58
RSD5E2	2530	2591	2.41	2617	3.44	2568	1.50
RSD5E1	2673	2683	0.37	2706	1.23	2677	0.15
RSD5H	2816	2856	1.42	2892	2.70	2785	1.10
RSD5D1	2960	3034	2.50	3041	2.74	2941	0.64
RSD5D2	3102	3191	2.87	3200	3.16	3067	1.13
RPO1H	361	371	2.77	384	6.37	366	1.39
RPO3H	1082	1108	2.40	1113	2.87	1085	0.28
RPO5H	1803	1951	8.21	1921	6.54	1842	2.16
IRSD1H	363	371	2.20	391	7.71	375	3.31
IRSD3H	1317	1348	2.35	1351	2.58	1368	3.87
IRSD5H	2618	2666	1.83	2726	4.13	2560	2.22

Indicator:

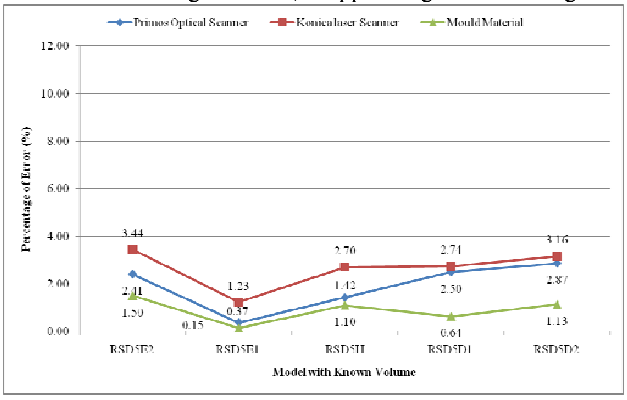
R = Regular Shape	SD# = Sloped Edge	E# = Elevated Base
IR = Irregular Shape	PO# = Punched Out	H = Homogenous Base
	# = Height	D# = Depressed Base

Models with Regular Base, Slopped Edge of 3mm height



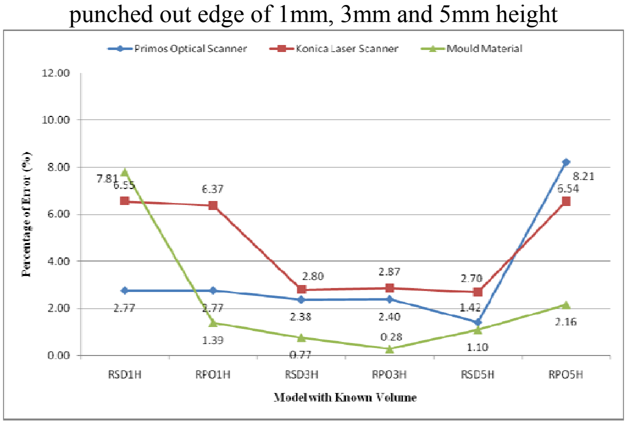
(a)

Models with Regular Base, Slopped Edge of 5mm height



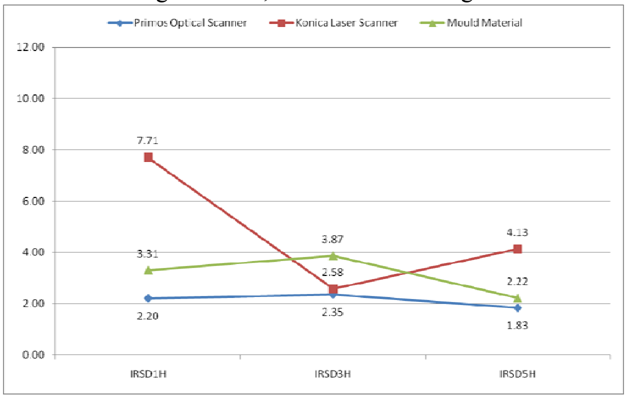
(b)

Model with regular base, homogenous base and slopped/ punched out edge of 1mm, 3mm and 5mm height



(c)

Models with Irregular shape, homogeneous base and slopped edge of 1mm, 3mm and 5mm height



(d)

Fig. 5 Graph of percentage error of volume computed using midpoint projection algorithm

However, there are limitations for both data acquisition techniques. From Table II, it can be seen that nearly all models using mould material technique have the lowest error in volume measurement compared to optical scanner followed by laser scanner. Volume measurement using mould material has percentage of error lower than 8%. Although it is accurate in volume cavity measurement, it can only serve as reference volume in comparing various volume measurement methods due to its invasive nature. The optical scanner (structured light) has an overall percentage of error lower than 5% whereas laser scanner (laser triangulation) has an overall percentage of error lower than 8%.

Fig. 5 (a) and (b) shows the shows the percentage of error for models with same attribution except difference in their height. Based on the observation, the 2mm elevated base (RSD3E2 and RSD5E2) always gives the high percentage of error result compare to others. As light always travel in straight line, the area after the protruded hill will appearing blur and causing the wrong calculation on the surface which shown in Fig. 6. It is obvious that the area with red circle indicate coarser surface compare to other area.

The height, shape and base of the model i.e. RSD1H-RPO1H, RSD3H- RPO3H, RSD5H- RPO5H are found to be almost the same attribution except difference in their edge, which bring to small different of each of their error percentage. It is proven from Fig. 5 (c). However, there is an exception for the experiment, which is RPO5H model. Fig. 7 shows the RPO5H model in which the percentage of error is high for both image taken by optical scanner and laser scanner. This is because the shadow occurs due to the projection angle over the boundary appeared in large area which leads to miscalculation of volume. Hence, this model is an outlier data that is neglected.

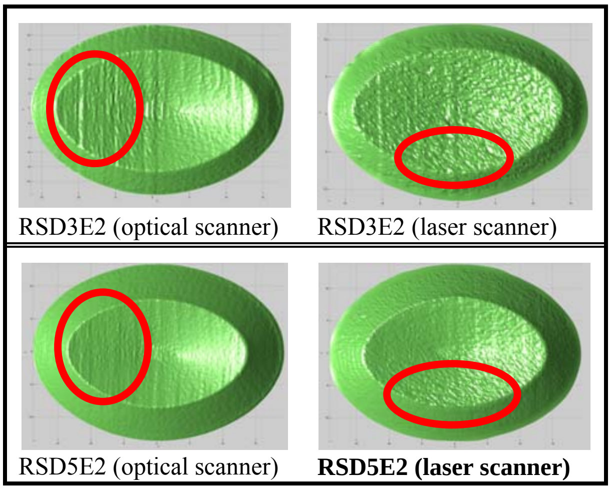


Fig. 6 RSD3E2 and RSD5E2

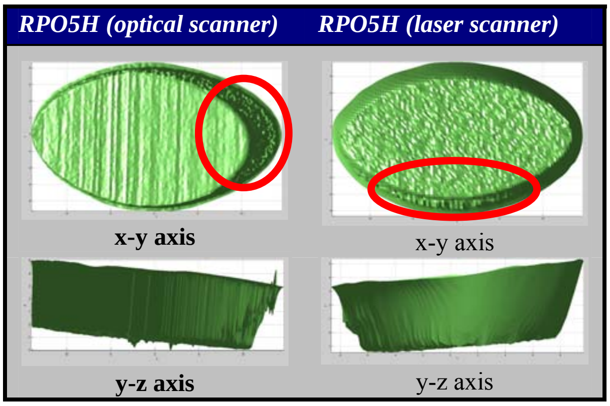


Fig. 7 RPO5H model

For the model with irregular base, sloped shape and homogenous base, the percentage of error is shown in Fig. 5 (d). Model IRSD1H shows percentage of error at 7.71% from laser scanner and 2.20% from optical scanner. In model IRSD3H, optical and laser scanner show 2.35% and 2.58% percentage of error whereas in model IRSD3H, percentage error for optical and laser scanner are 1.83% and 4.13%. Fig. 8 shows the IRSD5H model image that being captured from laser scanner. Based on the observation inside the red circle, the sharp edge is deviated from the original path. As mention in [16], scanner uses laser triangulation method are often unreliable near sharp edges due to specular reflections there. For the percentage of error lower than 10%, the method is considered reliable and accurate. For structured light technique with multiple wavelengths phase-shifting, each point is carrying a unique label that able to be distinguishable with neighbours and use triangulation calculation. More points on the object surface can be detected and it leads to the smoother and more natural of the generated surface. Eventually, it can help to provide more accurate result in volume measurement. Hence, fringe projection is more precise than triangulation, because it exploits the fine position or phase' of the projected stripe patterns at high precision [17].

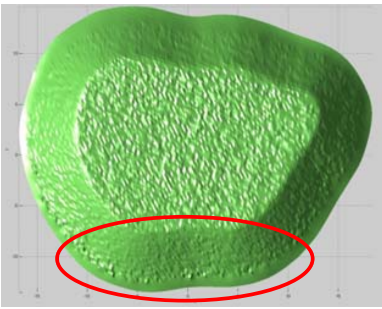


Fig. 8 Visual inspection on IRSD5H model captured from laser scanner

V. Conclusion

The study revealed that optical scanner is more reliable and accurate compared laser scanner. The R^2 optical scanner was 0.995671 whereas it was only 0.994050 for laser scanner. The volume computed using laser and optical scanner showed strong correlation with the reference volume using CAD model. Structured light and laser triangulation techniques show high percentage of error when the wound edge is equal or greater than 5 mm and the elevated base equal or greater than 2 mm.

By knowing all the limitation and the strength of the equipment capability and functional of the algorithm used, we can develop the biomedical measuring system as a useful adjunct to conventional clinical evaluation.

Acknowledgment

The research is collaboration between Universiti Teknologi PETRONAS (UTP) and Dermatology Department, Hospital Kuala Lumpur. The Clinical Study Proposal (NMRR-11-39-7990) was approved by the Clinical Research Centre, Ministry of Health Malaysia

References

[1] D. A. Perednia, "What Dermatologists Should Know About Digital Imaging," *J Am Acad Dermatol,* vol. 25, pp. 89-108, 1991.

[2] M. G. Woodbury, P. E. Houghton, K. E. Campbell, and D. H. Keast, "Development, Validity, Reliability, and Responsiveness of a New Leg Ulcer Measurement Tool," *Advances in Skin & Wound Care,* vol. 17, pp. 187-196, 2004.

[3] N. Kecelj-Leskovec, M. Jezeršek, J. Možina, M. D. Pavlović, and T. Lunder, "Measurement of venous leg ulcers with a laser-based three-dimensional method: Comparison to computer planimetry with photography," *Wound Repair and Regeneration,* vol. 15, pp. 767-771, 2007.

[4] T. Wild, M. Prinz, N. Fortner, W. Krois, K. Sahora, S. Stremitzer, and T. Hoelzenbein, "Digital measurement and analysis of wounds based on colour segmentation," *European Surgery,* vol. 40, pp. 5-10, 2008.

[5] D. Langemo, J. Anderson, D. Hanson, S. Hunter, and P. Thompson, "Measuring Wound Length, Width, and Area: Which Technique?," *Advances in Skin & Wound Care,* vol. 21, pp. 42-45 10.1097/01.ASW.0000284967.69863.2f, 2008.

[6] A. Shai, H. I. Maibach, and C. Ebooks, "Ulcer Measurement and Patient Assessment," in *Wound Healing and Ulcers of the Skin : Diagnosis and Therapy - the Practical Approach*, ed Dordrecht: Springer-Verlag Berlin and Heidelberg GmbH & Co. KG, 2005, pp. 89-102.

[7] MAVIS II: 3D Wound Instrument Measurement [Online].

[8] B. Albouy, Y. Lucas, and S. Treuillet, "3D Modeling from Uncalibrated Color Images for a Complete Wound Assessment Tool," in *Engineering in Medicine and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE*, 2007, pp. 3323-3326.

[9] C. Ozturk, S. Dubin, M. E. Schafer, S. Wen-Yao, and C. Min-Chih, "A new structured light method for 3-D wound measurement," in *Bioengineering Conference, 1996., Proceedings of the 1996 IEEE Twenty-Second Annual Northeast*, 1996, pp. 70-71.

[10] T. A. Krouskop, R. Baker, and M. S. Wilson, "A noncontact wound measurement system," *Journal of Rehabilitation Research and Development,* vol. 39, pp. 337-346, 2002.

[11] S. M. Boersma, "PHOTOGRAMMETRIC WOUND MEASUREMENT WITH A THREE-CAMERA VISION SYSTEM," *International archives of photogrammetry and remote sensing = Archives internationales de photogrammétrie et de télédétection /,* vol. 33, pp. 84-91, 2000.

[12] A. Malian, A. Azizi, F. A. van den Heuvel, and M. Zolfaghari, "Development of a Robust Photogrammetric Metrology System for Monitoring the Healing of Bedsores," *The Photogrammetric Record,* vol. 20, pp. 241-273, 2005.

[13] P. Plassmann and T. D. Jones, "MAVIS: a non-invasive instrument to measure area and volume of wounds," *Medical engineering & physics,* vol. 20, pp. 332-338, 1998.

[14] M. Callieri, P. Cignoni, P. Pingi, R. Scopigno, M. Coluccia, G. Gaggio, and M. Romanelli, "Derma: monitoring the evolution of skin lesions with a 3D system," presented at the Proceedings of the Vision, Modeling, and Visualization Conference 2003 Munich, Germany, 2003.

[15] A. Hani, N. Eltegani, S. Hussein, A. Jamil, and P. Gill, "Assessment of Ulcer Wounds Size Using 3D Skin Surface Imaging," in *Visual Informatics: Bridging Research and Practice*. vol. 5857, H. Badioze Zaman, P. Robinson, M. Petrou, P. Olivier, H. Schröder, and T. Shih, Eds., ed: Springer Berlin / Heidelberg, 2009, pp. 243-253.

[16] T. Várady, R. R. Martin, and J. Cox, "Reverse engineering of geometric models--an introduction," *Computer-Aided Design,* vol. 29, pp. 255-268, 1997.

[17] G. Frankowski, R. Hainich, S. Emerging Digital Micromirror Device Based, and Applications, III, "DLP/DSP-based optical 3D sensors for the mass market in industrial metrology and life sciences," *Proc SPIE Int Soc Opt Eng Proceedings of SPIE - The International Society for Optical Engineering,* vol. 7932, 2011.