Asian Journal of Scientific Research

ISSN 1992-1454

Asian Journal of Scientific Research 6 (3): 423-433, 2013
ISSN 1992-1454 / DOI: 10.3923/ajsr.2013.423.433

Comparative Study on Data Acquisition Techniques and Solid Reconstruction Algorithm for Quantitative Ulcer Wound Assessment

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ABSTRACT
Reverse Engineering (RE) is systematic evaluation of a part with the purpose of replication and improvement. Recently, its application has extended into the domain of biomedical engineering, where it is utilized in retrieving ulcer wound data from patient's body. Response to ulcer treatment whether the wound is healing or deteriorating is indicated by the size and volume of leg ulcer wound. Currently dermatologists assess the ulcer wound qualitatively which is subjective and differ between one dermatologist to another. This research focuses on applying RE to conduct a quantitative assessment of ulcer wounds and perform a comparative analysis using different algorithms for solid reconstruction and volume computation. This study also embarks on comparative analysis between two data acquisition techniques, laser triangulation and structured light method. Data acquisition is performed by utilizing non-contact optical 3D techniques such as laser triangulation and structured light method. Solid reconstruction is accomplished by midpoint projection algorithm and convex hull algorithm. Volume for ulcer wound models is computed using the volume computation algorithm which is integrated with solid reconstruction algorithms. A comparative analysis based on the results shows that structured light is more efficient than laser triangulation for data acquisition. The results also testify that convex hull algorithm is more reliable and accurate than midpoint projection algorithm for wounds with irregular boundary.

Key words: Reverse engineering, laser triangulation, structured light, midpoint projection, convex hull

INTRODUCTION
RE can be defined as the process of analysing an existing system to identify its components and their interrelationship and create representations of the system in another form or at a higher level of abstraction. In RE a product is evolved by acquiring data regarding the real part (Son *et al.*, 2002), it is a process of creating engineering design data from existing parts (Lee *et al.*, 2001). The steps of reverse engineering are shown in Fig. 1.

Recent advances have been made in the field of biomedical engineering which is based on the concept of RE. Quantitative assessment of ulcer wound is one such application of RE in biomedical engineering. Ulcer is a skin disease which can be defined as full thickness skin loss involving

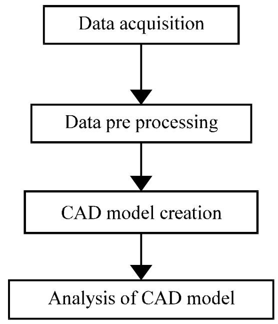


Fig. 1: RE steps

Fig. 2: Ulcer wound

damage to necrosis of subcutaneous tissue that may extend down to but not through, underlying fascia as shown in Fig. 2. The ulcer presents clinically as a deep crater with or without undermining of adjacent tissue.

Different types of tissues with different colour exist on ulcer wound surface as they progress throughout the healing process they are identified as, black necrosis, yellow slough, red granulation and pink epithelial tissue. At any one time, all the four tissues can be present on the ulcer wound surface. Discerning and assessing the amount of each type of tissue is an approved method of qualitative wound assessment. Qualitative method is widely used in clinical settings but has the disadvantage of being simple, subjective and more importantly difficult to qualify and quantify. Chronic wounds heal gradually which makes detection of small changes with visual inspection challenging. Dermatologist assessment is mainly limited to qualitative assessment which consumes times. Reliability, repeatability and accuracy are the issues related with qualitative wound assessment. In some cases a quantitative assessment is also performed by the dermatologists involving physical measurement of ulcer wound. The current quantitative methods involve measuring the length and breadth of wound by a scale or a measuring tape. Sometimes depth of ulcer wound is measured by inserting a swab inside the wound. All these methods provide a measurement of area or volume of the ulcer wound. But physical contact is necessary with the wound for such measurements causing pain and infection to the patient. In treatment approach a quantitative leg ulcer assessment with high efficacy and involving non-contact methods for data acquisition, can subjugate the issues related to current wound assessment methods. Research is in progress for different methods of quantitative assessment (Brown, 2003). This research sets out the objectives to conduct a comparative study for (1) effect of different techniques for data acquisition on volume computation and their accuracy (2) Suitability of solid reconstruction algorithms (Midpoint projection and convex hull (Hani *et al*., 2009)) for volume computation.

APPROACH AND METHODS

Data acquisition: Data acquisition is a significant element of quantitative wound assessment and it commences with the physical phenomenon or physical property to be measured. Optical methods of data acquisition are extensively employed as non-contact methods of data acquisition and are most popular with relatively fast acquisition rates. There are five important categories of optical methods which are Triangulation, Ranging, Interferometry, Structured lighting and Image analysis (Varady *et al*., 1997). This research implements laser triangulation method and structured light method of optical 3D scanning as non-contact techniques of data acquisition. Triangulation is a method which uses location and angles between light sources and photo sensing devices to deduce position. Various light sources are used but lasers are the most common light source used for triangulation (Sadlo *et al*., 2005). Laser triangulation is a technique of distance measurement using laser. A high energy light source is focused and projected at a pre specified angle at surface of interest. A photosensitive device senses reflection of the surface and then by using geometric triangulation from the known angle and distances, position of surface point relative to a reference plane can be calculated (Sadlo *et al*., 2005), Fig. 3 depicts the working principle of laser triangulation method.

Structured light method involves projecting pattern of light upon a surface of interest and capturing an image of the resulting pattern as reflected by the surface (Valkenburg and McIvor, 1997). The image must be then analysed to determine co-ordinates of data points on the surface. Structured light technique can acquire large amounts of data with a single image frame but the analysis to determine positions of data can be rather complex. This method allows robust and accurate data acquisition of objects with arbitrary geometry and for a wide range of materials

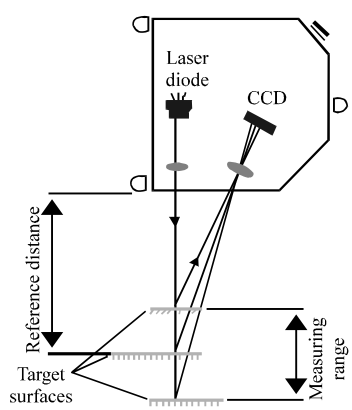


Fig. 3: Laser triangulation method

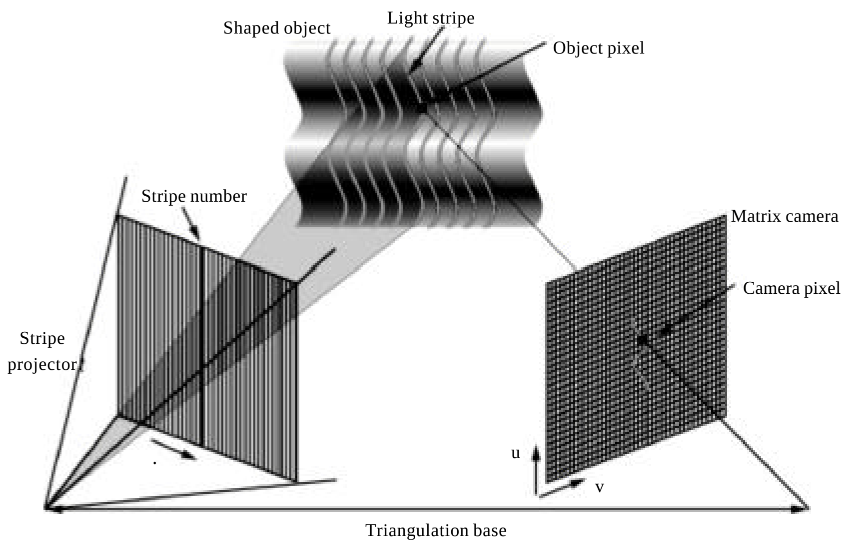


Fig. 4: Structured light method

(Valkenburg and McIvor, 1997). The projector projects a coded stripe pattern on the part and a photosensitive device acquires data in form of image. Hence for each visible point on the part there is a corresponding stripe number (stripe value) and image location (pixel coordinates) (Lee and Requicha, 1982) Figure 4 depicts the working principle of structured light method.

Solid reconstruction: Solid reconstruction is another significant operation anterior to volume computation. Two algorithms, Midpoint projection algorithm and convex hull algorithm are employed for solid reconstruction of the acquired data.

Midpoint projection: Midpoint projection algorithm constructs a solid by adding more points (midpoint) (Abdul Rani *et al*., 2011). Here, a solid is reconstructed from the 3D CAD model by colligating all the triangular faces to a midpoint creating many tetrahedra as shown in Fig. 5. The midpoint is calculated from a number of points in boundary of the wound. The algorithm works as follows:

Convex hull: Approximation encloses all the vertices representing the surfaces in the smallest polyhedron. The construction of convex hull is performed by growing simplex vertex by vertex constructing tetrahedra shapes (Varady *et al*., 1997) as shown in Fig. 6. A convex hull is constructed by firstly building a tetrahedron using 4 points (Delaunay 3-simplex); which is used as a seed upon which the remaining Delaunay tetrahedra crystallize one by one. Next, each triangular face of tetrahedra is used as a base from which the vertex representing the apex of adjacent tetrahedra is searched. A convex hull, CH (V) is the smallest polyhedron in which all elements of V represent its boundary or occur to be in its interior (Varady *et al*., 1997). The algorithm works as follows:

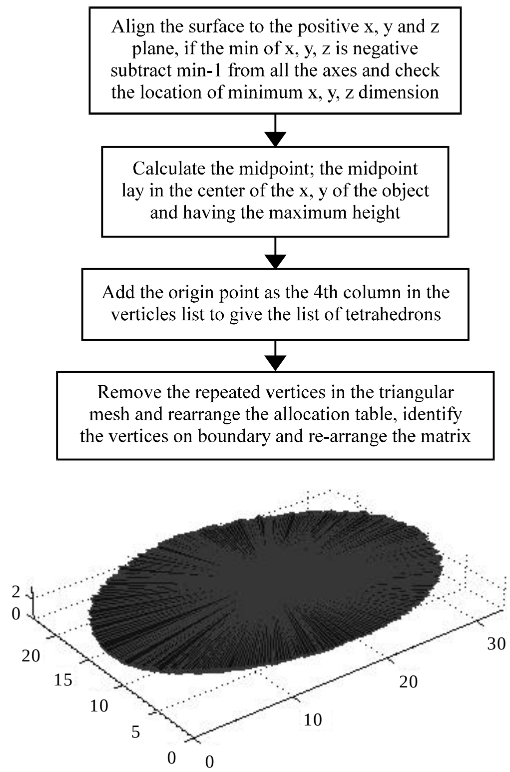


Fig. 5: Solid reconstruction using midpoint projection

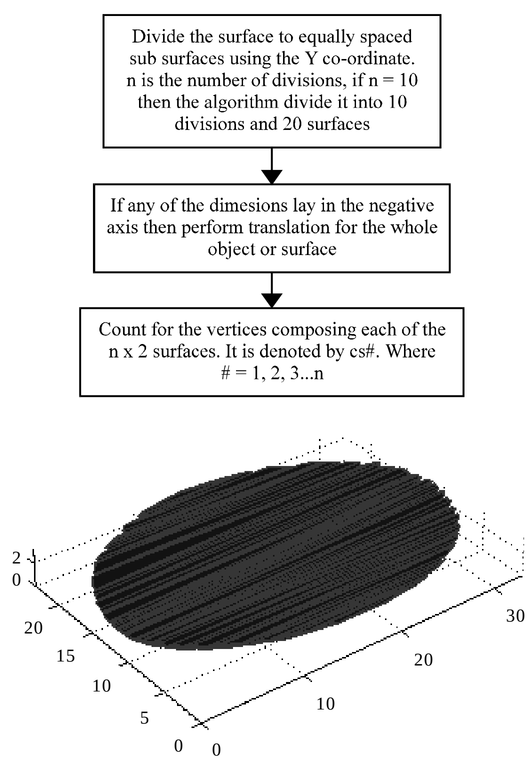


Fig. 6: Solid reconstruction using convex hull

Volume calculation: A tetrahedron is a polyhedron constituting four triangles and each vertex of this polyhedron is composed by the intersection of three vertices. For a tetrahedron with vertices P1 = (x1, y1, z1), P2 = (x2, y2, z2), P3 = (x3, y3, z3) and P4 = (x4, y4, z4) the volume is given by Eq. 1:

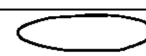
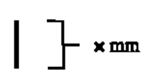
$$V = \left(\frac{1}{3!}\right)\begin{vmatrix} x_1 & y_1 & z_1 & 1 \\ x_2 & y_2 & z_2 & 1 \\ x_3 & y_3 & z_3 & 1 \\ x_4 & y_4 & z_4 & 1 \end{vmatrix} \tag{1}$$

To compute the total volume, the volumes of each distinct tetrahedra is calculated first and then are integrated to get the total volume of the reconstructed solid [5]. This can be represented as, volume of 3D object =Σ Vj (j = 1 to N), where N is the number of tetrahedrons.

Methodology: An ulcer can be modelled in various attributes according to their shapes, sizes and geometry. The models are classified based on four attributes viz., boundary, edge, base and depth as shown in Table 1.

In this study, models imitating ulcer wound with different attributes were used. Data pertaining to these models is acquired by two data acquisition technique viz., laser triangulation (Konica Minolta 3D laser scanner) and structured light (Primos optical 3D scanner). The two data acquisition methods and solid reconstruction techniques for volume computation are used on different models of ulcer wounds and comparative analysis for the models is conducted on the basis of accuracy (Fig. 7).

Table 1: Four attributes of wound

Attributes	Descriptor	Schematic
Boundary	Regular	
	Irregular	
Edge	Sloped	
	Punched Out	
	Undermined	
Base	Elevated	
	Depressed	
	Homogenous	
Depth		

Abdul Rani *et al*. (2011)

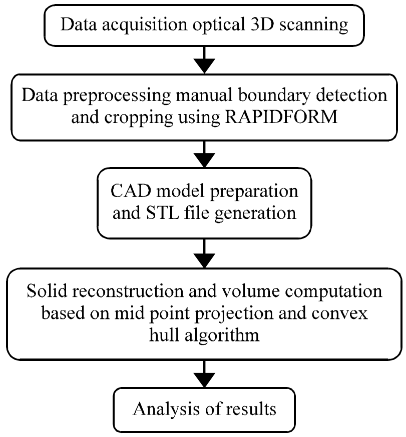


Fig. 7: Research methodology

RESULTS AND DISCUSSION

The volume is computed for different prototypes of ulcer wounds prior to which operations such as solid reconstruction of the CAD model is performed by implementing Midpoint projection algorithm and convex hull algorithm to the pre-processed data acquired in the form of 3D image from Laser triangulation and Structured light method, the calculated volume is further analysed for difference in volume in computation, when both solid reconstruction and volume computation algorithm are implemented to the data acquired by both data acquisition techniques, the difference in volume values are plotted for each data acquisition method and for each solid reconstruction and volume computation algorithm. It is observed that for two crops of an image of same model there is a difference in volume. This difference is more significant for the data acquired by the laser 3D scanner if compared to data acquired by optical scanner. Another reason for the difference in volumes is noise in the acquired data as shown in Fig. 8.

The difference in volume is plotted for each sample and a polynomial fit for the plotted curve is generated, the values of difference in volume are analysed and results are deduced. From the plot of difference in volume it can be observed that when employing optical scanner for data acquisition, the range of difference in volume is minor (Fig. 9, 10) except for one or two values but with laser scanner the range of difference in volume is prominent (Fig. 11, 12). From Fig. 9 it can be noticed that when using Midpoint algorithm for data acquired by optical scanner the values are dispersed in a broad range on both side of fitted curve, see values in circle 159.3 and -187.8 the average difference 6.38 and standard deviation 97.5, it was noted that these difference in volume are for a prototype with irregular boundary. Whereas from Fig. 10 which is plot for convex hull algorithm for data acquired by optical scanner it can be observed that dispersion of difference in volume about the fitted curve is prominently less if compared to midpoint projection algorithm and it was also noted that for same model with irregular boundary the difference in volume are very less see values in box, -20 and -34 with average difference 15.5 and standard deviation of 43.5.

When Laser scanner is employed for data acquisition it can be observed that for midpoint projection algorithm figure as well as for convex hull algorithm, the range of dispersion of difference in volume is very broad shown by the values in circle in both Fig. 11 and 12. The mean

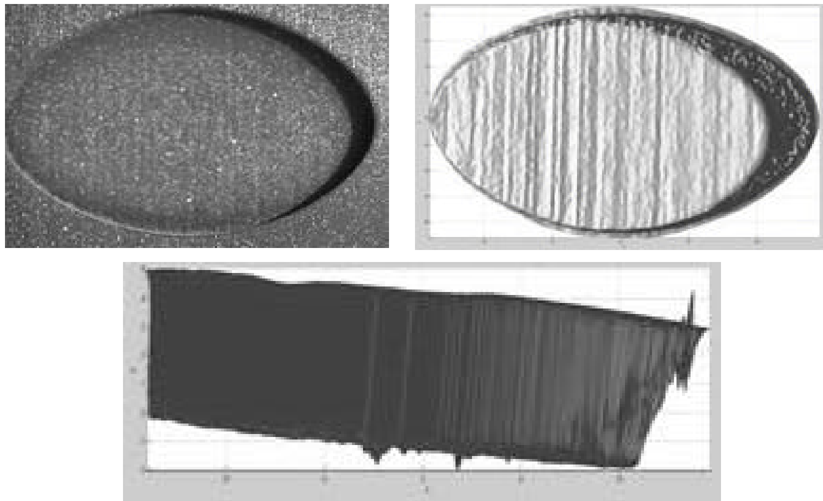


Fig. 8: Noise in data acquired by 3D scanner

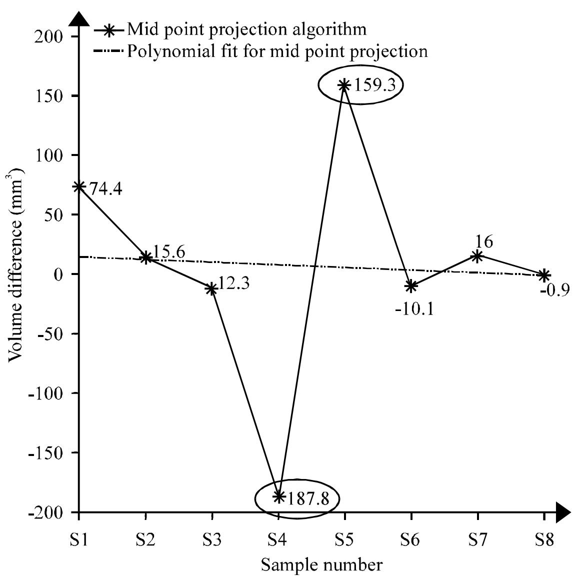


Fig. 9: Plot of volume difference for mid-point projection using optical scanner

difference and standard deviation for Fig. 11 are 30.31 and 71.6, respectively whereas the same for Fig. 12 are 13.4 and 73.5, respectively, indicating the inefficacy in the data acquisition by laser scanner. This may also be caused of the noise that appears in form of shadow and which is caused due to the projection angle over the boundary, appeared in large area which leads to miscalculations of volume. The other reason for this difference in volume is that, edge detection and boundary cropping is user discrete or is performed manually. Although the optical scanner can give a meliorate data acquisition if compared to laser scanner, it is not flexible when it comes to change

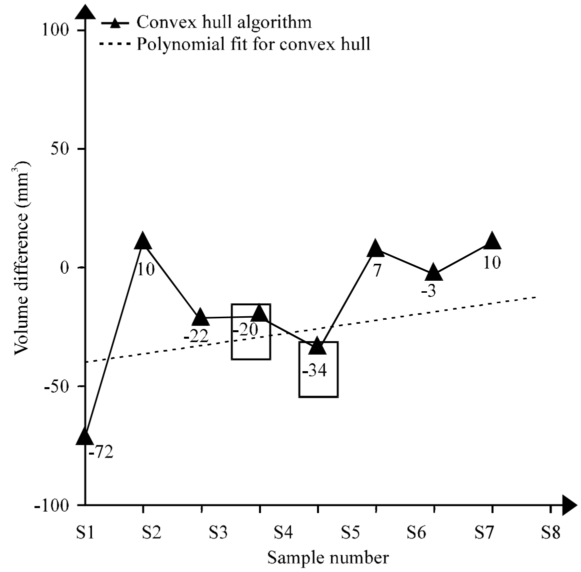


Fig. 10: Plot of volume difference for convex hull using optical scanner

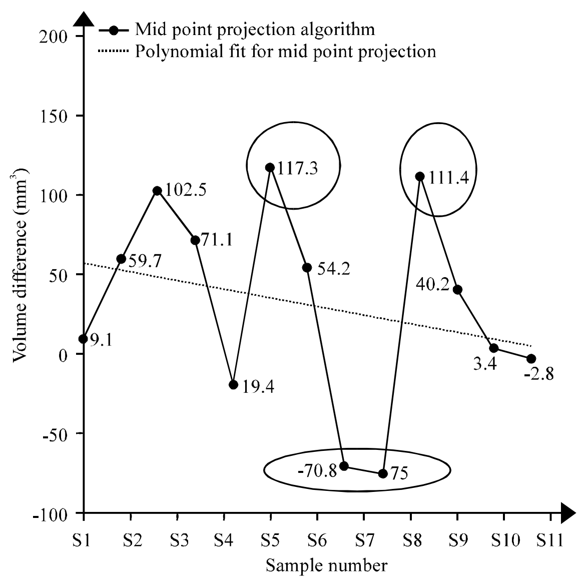


Fig. 11: Plot of volume difference for mid-point projection using laser scanner

of angle or change of position of the camera, it is fixed always with respect to the sample to be scanned but in case of laser scanner this flexibility to change the position of scanner, angle of scan, the distance between the camera and the sample is always present.

As mention by Varady *et al.* (1997), scanner uses laser triangulation methods are often unreliable near sharp edges due to specular reflections there and for the difference in volume 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 is 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.

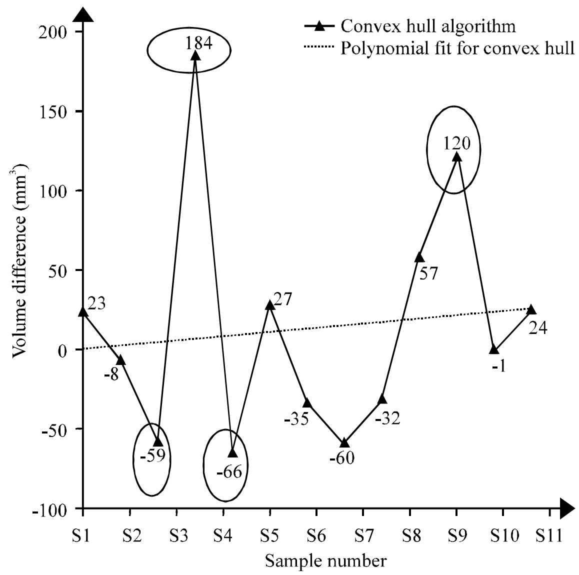


Fig. 12: Plot of volume difference for convex hull using laser scanner

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 (Frankowski and Hainich, 2011).

CONCLUSION

This study exhibits that the accuracy of the data acquired by structured light is better if compared to data acquired by laser triangulation. The result analysis also leads to conclude that solid reconstruction for irregular shapes by convex hull algorithm is more reliable and accurate than the midpoint projection algorithm. Also, it can be concluded that one significant factor for difference in volume in measurement is the noise arising from data acquisition attributed to sharp edges and shadow. By further study related to the limitation of the equipment for data acquisition techniques and functionality of various algorithms for solid reconstruction can develop a better tool for quantitative assessment of ulcer wounds can be developed.

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