Three-dimensional reconstruction and surface extraction of lower limbs as visualization methodologies of ecchymosis*

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***Abstract*— This paper presents a computational system for three-dimensional reconstruction and surface extraction of the human lower limb as a new methodology of visualizing images of multifaceted ecchymosis on the lower limbs. Through standardization of image acquisition by a mechanical system, an algorithm was developed for three-dimensional and surface reconstruction based on the extraction of depth from silhouettes. In order to validate this work, a three-dimensional model of the human lower limb was used inside a virtual environment. At this environment the mechanical procedure of image acquisition was simulated, resulting in 100 images which was later submitted to all algorithms developed. It was observed that the systems for three-dimensional reconstruction and surface extraction of the object were able to generate a new visualization method of the lesion. The results allow us to conclude that the developed systems provided adequate three-dimensional and two-dimensional visualization of the surface of the simulated model. Despite the lack of experiments with real ecchymoses, the systems developed in this work show great potential to be included in the standard methods for the visualization of ecchymoses.**

I. INTRODUCTION

The ecchymosis, defined as hemorrhagic spots on the skin or mucous membrane, are characterized by the flow of blood inside the cutaneous tissues, forming a stain without elevation, with undefined shape and a variable coloration from blue to purple, being dependent on age of the wound [1-3].

Besides the appearance and aesthetics of the wound, the ecchymosis may cause pain to the patient, thus leading to the need of developing procedures to accelerate the absorption of the lesions. They are currently object of scientific and clinical studies where researchers aim to understand and to reduce the impact of the wound on the body during a certain time [4-11].

For extensive multifaceted ecchymosis on lower limbs, the current procedure being used on researches is the observer-object system, where the observer (photographic camera) stays static while the object (patient) changes its spatial position to achieve different photographic angles [12].

Despite this methodology being capable of acquiring images of the whole surface of the limbs, the generated result is not optimized for clinical visualization since the overlapping limbs and geometrical distortions, caused by the variation of depth of the object, creates a confusion factor.

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Due to the lack of an adequate system to visualize multifaceted ecchymosis on the lower limbs, this paper aims to create a new visualization methodology for images of ecchymosis on the lower limbs through the development of a computer software for three-dimensional reconstruction and surface extraction of the object of study, allowing a dynamic and continuous visualization of it.

II. METHODOLOGY

Through the inversion of the observer-object system used on recent researches, it is possible to develop and apply a three-dimensional and surface reconstruction algorithm.

This inversion consists on the static placement of the patient's lower limb along with a radial movable photographic camera. This arrangement allows an accurate and controlled image acquisition.

A. Three-dimensional reconstruction

Whereas the conventional clinical analysis observes a real object through the physical variation of the visualization region, it is possible, then, to approach this observation methodology through the three-dimensional reconstruction of the real object inside a virtual environment, maintaining the user's control of the visualization region.

The 3D-reconstruction of a real object can be achieved through several ways [13-23]. Since the arrangement adopted in this paper allows an accurate and controlled image acquisition, it is possible to simplify the approach for the three-dimensional reconstruction of the lower limb. Thus, this task is done through silhouette based methodologies [14-19,21].

The algorithm developed for this task consists on the extraction of silhouettes from images acquired at a fixed step angle followed by the extraction of the border for each image. Based on the premise that the distance between a point on the border of a silhouette and the rotation axis of the object equals to the depth of this point, ninety degrees phased out from the acquisition angle, it is possible to extract the three-dimensionality of the objects surface, as depicted in Fig. 1.

Mathematically, it is possible to extract the rotation axis of the object through (1), where $RotationAxis$ is the scalar value of the rotation axis, $nImages$ is the number of images and $meanDist$ is the mean distance between the border D of each image.

$$RotationAxis = \sum_{j=0}^{nImages} \frac{meanDist_j}{nImages} \qquad (1)$$

Through the methodology presented, the depth of each point of the border (Δ) along with each image acquisition

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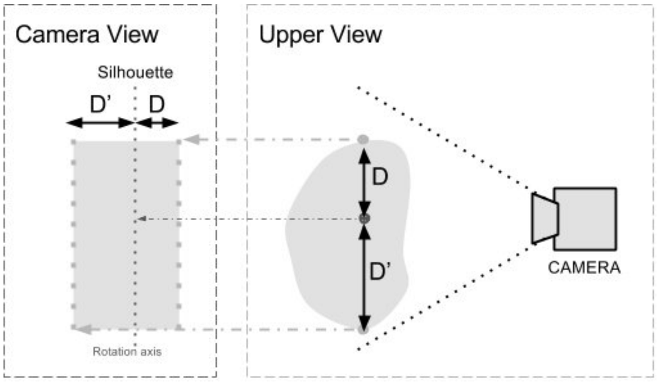

Fig. 1. Illustration of the three-dimensional depth extraction methodology.

angle (Θ) and the point height position (N) represents the surface of the object on the polar coordinate system, which can be transformed into a point cloud [24] through (2).

$$f(\Delta, \Theta, N) = [\Delta \cos(\Theta), \Delta \sin(\Theta), N] \quad (2)$$

The resultant point cloud represents a finite set of points which belongs to the surface of the real object. Though, since those points are not a surface, it is necessary to apply a triangulation method [25-27], wrapping those points to create a virtual surface.

Since the methodology used to extract the point cloud provides known parameters, it was possible to apply a simple triangulation algorithm which consists of the connection of each point with its neighbors forming triangles. As result, the triangles form the surface of the object, which is the three-dimensional model.

B. Surface extraction

Although the methodologies presented so far provide the reconstruction of a real object into a three-dimensional model, they do not provide the color intensity information which belongs to the surface of the object.

Thus, in order to fully reconstruct the object into a virtual environment, it is necessary to extract its surface and to apply it over the three-dimensional model.

The extraction of continuous information in form of image, or texture [28], can be achieved by the sampling of pixels from a certain region of each image acquired, where this region is set around the previously extracted rotation axis.

The dimension of each region is defined by the number of samples required to correctly reproduce the surface of the object. The number is defined by the geometric projection of curve connect by the depth of the current point and its neighbor, acquired on the next step angle, as depicted in Fig. 2. Mathematically, the sample number is calculated through (3).

$$sampleSize_j = radius_{j+1} \times \sin\left(\frac{360^o}{nImages}\right) \quad (3)$$

After the sampling, all pixels are then ordered and grouped into a single image, being coherent with the direction,

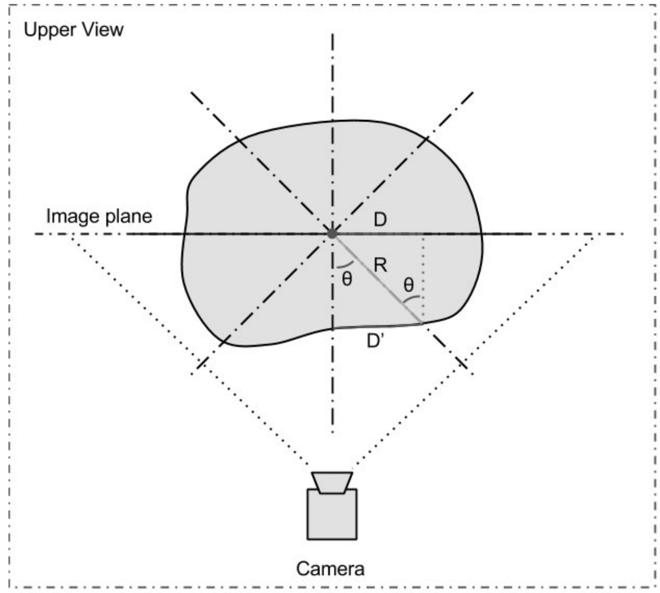

Fig. 2. Illustration of the geometric projection used to determine the number of samples needed.

size and characteristics of the images acquired. Then, this resultant image is mapped according to the triangulation applied on the point cloud and, later, each segment of image is applied into the model's triangles, forming the colored surface of the virtual object.

On the other hand, since the texture extracted from the real object represents a continuous image of the whole surface, it provides a single broad view of the object allowing the specialist to analyze the ecchymosis as whole. Thus it becomes adequate as an alternative visualization method, also enabling the use of image processing tools for quantitative data extraction.

C. Simulation and prototyping

Due to the need of the development of an equipment for acquiring images according to the proposed methodology, it was simulated a virtual acquisition system using a three-dimensional model of a human lower limb, shown in Fig. 3, inside a virtual environment.

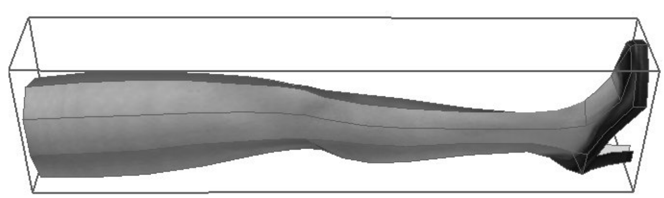

Fig. 3. Three-dimensional model of a human lower limb inside a virtual environment.

The process of visualization of the model inside the environment is done through a virtual camera. This camera was aligned and centered with the model at a fixed distance and height, however those values are dependent only of the region of interest to be acquired, being defined according to each case. Through rotation of the camera with a fixed step angle of 3.6 degrees, one hundred images of the model were acquired.

In order to test the methodologies defined on this work, a prototype software was developed using the .Net framework along with the XNA Software Development Kit (SDK). The main features of the prototype are: loading image files, extracting silhouettes and point cloud, triangulation of point cloud, extracting the surface and application of texture image, and show the results.

III. RESULTS AND DISCUSSIONS

Through the application on the prototype software of the images acquired by simulating the acquisition methodology, the results presented in this section are discussed according to the expectations and preliminary tests.

After the images are loaded on the prototype, it process the images and extracts the silhouettes and data necessary to reconstruct the three-dimensional model. Then, as result of the reconstruction process, it shows the triangulated point cloud, Fig. 4(a), the model without texture, Fig. 4(b), and the model with applied texture, Fig. 4(c).

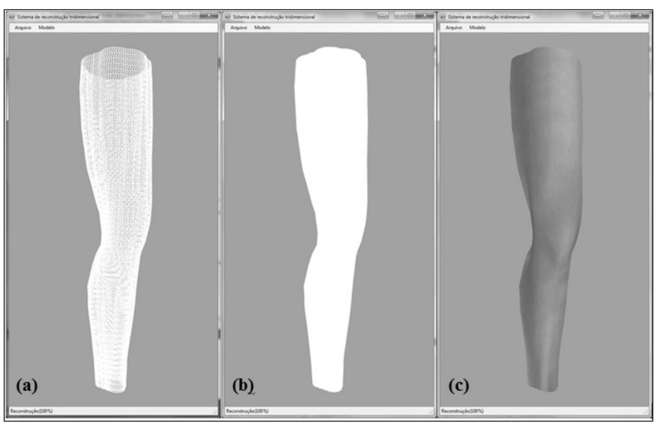

Fig. 4. Result of (a) point cloud extraction, (b) surface reconstruction and (c) addition of texture to the resulting model.

According to the results presented in Fig. 4, the algorithms developed for three-dimensional reconstruction works, providing the points of the surface of the object in a virtual environment. Although the algorithm works, it is still necessary to compare the original and reconstructed model in order to evaluate the efficiency of the technique. From this result it is also possible to visualize that the number of images acquired affect the shape of the model, where a higher number of images provide better resolution.

On the other hand, it is hard to determine if the results would be replicated outside the virtual environment, since it requires a precise and controlled acquisition methodology, which might require a cautious development of an equipment. Such equipment is under development and consists of an electromechanical control system along with an automated software to acquire images under the right conditions.

The surface extraction algorithm, which used the same input images as the reconstruction software, has returned as result the image in Fig. 5.

Fig. 5. Resultant image of the surface extraction algorithm.

Figure 5 shows that the whole surface of the object was correctly extracted and inserted into a single image. The image does not shows any noise or discontinuity, although the surface seems to be deformed, all points have been drawn and it shows the corresponding geometry of the surface when stretched.

However, under real conditions, it is expected that external noises, such as uneven illumination, will have a major influence on the resultant image. This should be corrected by using the automated system, under development, with the addition of controlled illumination and post-processing algorithms for noise reduction.

The patient's movement may also affect the surface extraction algorithm, thus being important to provide a stabilization system, such as handrail and foot-stand, in order to acquire stable and centralized images.

The results for the three-dimensional reconstruction and surface extraction shows that is possible to use the defined methodology to provide an alternative visualization of the human lower limbs.

By taking into consideration that the three-dimensional model with texture is inserted inside a virtual environment, where it is possible to manipulate dynamically the visualization angle and zoom, it shows that this alternative is close to the real observation methodology.

On the other hand, the two-dimensional image generated through the extraction of the surface provides a wide variety of possibilities beyond the simple visualization of the ecchymosis, since it makes possible to apply image processing techniques, such as feature extraction and image enhancement algorithms, improving the evaluation of procedures applied onto the wounds.

IV. CONCLUSIONS

Through the presented results and discussion, it is possible to conclude that the proposed and developed algorithms work, where the generated visualization modes might achieve the purpose of this work, providing better visualization of the ecchymosis and reducing the confusion factor created due to its characteristics.

As future work, it is necessary to finish the development of an equipment capable of acquiring real images of patients so the system can be submitted to reliable testing, such as the measure of deviation from a real model to the reconstructed one. Also, a validation methodology must be created in order to evaluate the real advancement provided by this system, offering for professionals tools to quantitatively evaluate the evolution of the ecchymosis.

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