3D Models for Leg Prosthesis

The first step to measure the stub's fitting into a prosthetic device

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Abstract—**A system for (tri-dimensional) 3D modeling of the leg prosthesis and posterior limb-prosthesis fitting measurement is being developed. This is a real problem, which needs to be solved in order to diminish the complications caused by a lack of adaptation between the patients stub and the device. These complications consist in mechanical stresses and possible injuries in the patient's limb. The system can segmentate a randomly projected laser line on the inner surface of the prosthesis and detect the geometric center of the prosthesis' recorded image. This work is at an early stage, and the final system should be capable of projecting a laser circumference on the prosthesis and use it as a scanner to measure its dimensions. If properly developed and functional, the system would fill a gap in the existent technology as it allows prosthetists and doctors to do a more accurate and faster design of the prosthetic devices and be capable of giving a better comfort to the amputee.**

Keywords-component; leg prosthesis, fitting, laser scanner, image processing, 3D data

I. Introduction

Artificial legs are mechanical devices which are expected to restore, even partially, the amputated patient's normal leg function, both for above-knee and below-knee amputation. Several developments occurred since 1861, and leg prosthesis evolved from a non-functional, leg mimical device made of wood and iron into the twentieth century's strong and lightweight prosthesis [1]. Polymeric materials, such as modern plastics and light metal alloys were responsible for the creation of a functional device, and even for the development of better pigments and the optimization of the production steps yielded to a realistic-looking prosthesis [1]. Robotic, or bionic, prosthesis and myoelectric prosthetic devices were a very important innovation as they use electrical signals from the patient's muscles in order to control the movement of the limb based on the nervous system's information [1]. Although being a very advanced field of research, a bionic prosthesis shares a problem with a conventional one: the coaptation, or fitting, between the device and the patient's stub sometimes is not perfect. This might be due to the production steps.

Prosthesis are essentially manufactured with a double-step procedure [2] that uses plaster bandages to create a cast of the amputated limb. This cast is manually molded by the technician, seeking a good resemblance between the stub and the cast [2]. The final cast of the stub is, under vacuum, covered with a plastic socket of polypropylene [2], which assumes its shape. Some deformations, especially in the fleshy parts [2], are added to the cast, so the final configuration of the prosthesis is different from that of the resting limb. That can lead to the non-fitting of the device, and the process needs to be repeated. On the other hand, although a good fitting is desired, it is not always achieved, because the production is very imprecise with accuracy problems dependent on the used instruments [2], the operators' skills [3-4] and the plaster mechanical properties at the measurement time and the status of the patients' stub [2]. In fact, the lack of fitting between the involved structures can lead to injuries, differential pressure distribution over the limb, thus causing discomfort. If the patient is a child or an adolescent, its limb will grow and sportsperson will have an addition of muscular tissue, which will compromise the fitting process. These factors are responsible for the prosthesis substitution after some time, and the patient needs to be involved again in the mentioned procedures. Even routine consultations are based on the subjective evaluation of the fitting, performed both by the patient and the doctor.

In recent years, several methods were developed to assess the 3D model of the patient's stub (essentially an adaptation of machine vision systems) [5-6], but none was developed in order to analyze the inner structure of the prosthesis. The present work intends to create a non-invasive system capable of quickly measure the prosthesis inner structure and compute its fitting with the 3D model of the stub. This will diminish the fabrication time and increase the accuracy of the production. A long-term goal is to allow doctors to make a quicker and accurate diagnosis, determining if a new prosthesis is needed and which characteristics it should have, creating the possibility of an automatic, non-manufactured production of prosthesis. At the same time prosthetists could use this system for an auto-evaluation, comparing the inner surface scanning to the 3D model of the stub and determine if it would fit adequately or not.

Nowadays, laser light is broadly used for structure scanning, allowing the recording of several frames, which can, then, be analyzed towards the creation of a 3D model. Our approach will consist on the projection of a circumference over the inner surface of a conventional prosthesis, in order to enable the radial measurement of its dimensions along the prosthesis height. The work is in its very early stages, namely the image recording, line segmentation and determination of the geometric center of the prosthesis' recorded image. This center will be the exact same center of the black circumference observed in the bottom of the prosthesis (Figure 2 a). In the future, the laser line should be replaced by a laser circumference.

II. Image Processing and Analysis

In the dark, a laser line was projected in the inner surface of a conventional leg prosthesis using a laser emitting at 650 *nm* with 5 *mW* power. The procedure was recorded using a Sony EyeToy® camera with *640x480* pixels resolution. Frames were obtained and processed using the Matlab 2011®. For each frame, the red component (Figure 1 b) of the original *RGB*

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image (Figure 1 a) was extracted and then binarized (Figure 1 c). It was applied a median filter and then a treshold of 0.95 (empirically determined) to this image, because the line is the brightest object in the image. Objects contacting the borders of the image were not considered and the remaining ones were labeled. Then, the algorithm searched for the object with the highest area, which ideally will be the line (Figure 1 d). The geometric center of the prosthesis was obtained using the Hough Transform. Briefly, for each frame, the green component was extracted to a better background definition. Then, the negative of the latter image was obtained, binarized with a 0.81 threshold level (empirically determined) and thinned. The Hough Transform algorithm for circular lines [7] was applied, searching for objects with a radius near 47 pixels, creating a Hough Space (Figure 2 b). The intersection of the several circumferences of this space occurs on the center of the prosthesis, allowing us to get its coordinates (Figure 2 a).

III. RESULTS AND DISCUSSION

The results presented in Figure 1 proved first analysis to be effective, accurate and consistent with the expected results. It was possible to individualize a single thin line (1 pixel thickness), with no relevant loss of information, for every frame of the recorded videos. The resulting line presented the same shape of the original laser line, and eventual light reflexion (see Figure 1 a, next to the fingers) is not considered because it is not as bright as the projected line. These results showed the developed algorithm to be immune to the presence of artifacts on the image, such as the outside of the prosthesis or the hand of the operator. The final system will not have these problems so, the absence of errors shows that, in controlled conditions, it would be possible to diminish even more eventual errors due to this step.

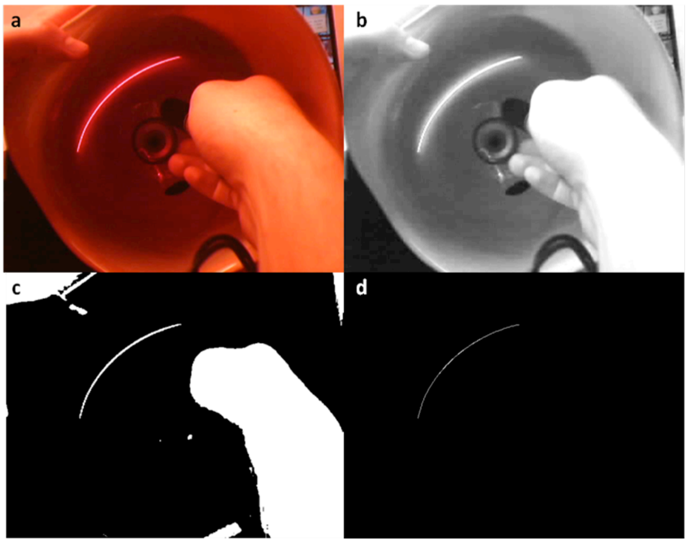

Figure 1. Results obtained for the line segmentation: a) represents the original frame, b) shows the red component of the original RGB image, c) shows the binary image resulting from thresholding and d) the segmented line.

It seems risky to choose the object the biggest area, but, analyzing Figure 1 c, it is easy to understand that, once eliminated the objects contacting the borders (objects from outside the prosthesis), only the line and small artifacts remain (result of the thresholding operation). This will also work when a circumference is used, because the area of the object will be even bigger. The center detection algorithm is very exact, returning the point represented on the Figure 2 a, which is the exact center of the prosthesis. As the relative position of this point will always be the same for each frame during the scanning analysis (the camera will not change position), the distance of the projected line points will be measured considering this center.

Further work must be developed, in order to construct an automatic physical system capable of projecting a laser circumference on the inner surface of the prosthesis, acquiring, at the same time, the projected circumference while moving it along the prosthesis. Once the system is working, it would be important to compare the obtained digital model with the plaster cast, in order to understand how much fitting it would be possible to gain with this approach. Then, the system can be easily adapted to be used in different applications. In the prosthesis field, it could be useful for working with the arm prosthesis too, for instance.

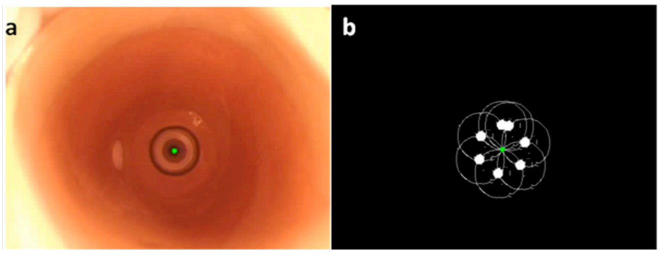

Figure 2. Results obtained for the center detection. In a) the original image is represented simultaneously with the detected center (green spot) and b) is the obtained Hough Space for center detection (intersection point is shown in green).

IV. CONCLUSIONS

The stub-leg prosthesis fitting is a real and unsolved problem, which affects amputated individuals and can be decisive to the efficiency of the prosthetic device. First results show that it is possible to perform the segmentation of a laser line from the background image, maintaining its original characteristics. As the segmented line was thin and the center detection were accurate, even with a non-controlled laser projection, it is possible to conclude that this step presents a solid base for future developments.

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