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A Circumference-Measurement Method Using a Model of a Leg and a 3D Camera*

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***Abstract*— The circumference of a limb is an important parameter in the follow-up of an edema. Recently, several methods of measuring the circumference on a limb using 3D cameras have been proposed. However, the 3D cameras used are expensive and difficult to implement in general medical facilities. In this study, we propose a circumference-measurement method using a Structure Sensor. First, the leg is photographed and unnecessary background objects are removed from the obtained point cloud. Next, a cross-sectional view is obtained by slicing the point cloud at the specified leg height. Finally, the circumference measurement at a specified leg height is performed by calculating the circumference using the acquired cross-sectional view. Using this method, the leg circumferences of two healthy subjects were measured at two points. For comparison, circumferences were also measured with a measuring tape. The difference between the values estimated using our method and the measured values was generally less than 0.5 cm.**

I. Introduction

Edema is the swelling of the limbs caused by the accumulation of excess fluid in the body. In particular, lymphedema, which is caused by resection of lymph nodes in the arms and legs (e.g. in the treatment of breast cancer, uterine cancer, prostate cancer, etc.), can result in large swelling of the arms and legs and interfere with daily activities, as shown in Figure 1. In such cases, the patient with lymphedema should be examined by a physician and undergo continuous treatment and observation. For treatment, self-management, such as wearing elastic stockings, as shown in Figure 2, is necessary [1,2]. In addition, regular observation of the degree of edema allows us to monitor the effects of these treatments and allows early detection of complications.

The main method for monitoring such edemas is to measure the circumference of the patient's legs or arms [3-5]. This generally involves the use of a measuring tape, as shown in Figure 3. However, this takes time and is burdensome to the patient.

Figure 1. Edema.

Figure 2. Elastic stocking.

Figure 3. Measurement with a measuring tape.

Therefore, a measurement method using a 3D model of the patient's leg or arm has been proposed in recent years [6-9].

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Previous studies include measurements of lower-extremity volume using GRASP, and limb circumference and volume measurements using a Pero Meter. However, the equipment used in these studies is expensive, making it difficult to disseminate these methods in medical practices and home care.

In this study, we adopted the method of measuring the volume of the lower limbs using a relatively inexpensive 3D camera, called a Structure Sensor [8,10] (Figure 4).

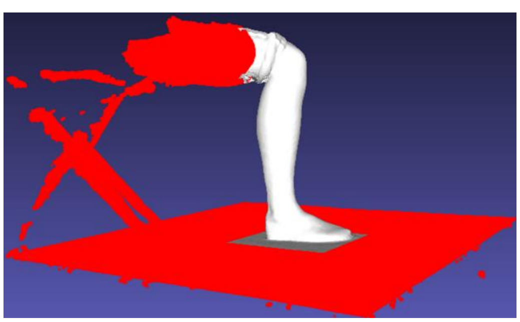
Figure 4. Structure Sensor.

II. Pre-processing of acquired 3D models

The first step in our method is to remove unnecessary background objects and floor surfaces reflected in the 3D model acquired by the Structure Sensor.

A. Extraction of the leg structure

The 3D model acquired by the Structure Sensor includes unnecessary objects other than the target, such as chairs. Therefore, we manually deleted all parts of the leg other than the part to be measured. For manual processing, we used MeshLab to edit the 3D model [11]. MeshLab is open-source software for 3D data editing that allows the user to delete, rotate, and move point clouds and meshes. The following is a description of the procedure for working with MeshLab.



(a) Before deletion.

(b) After deletion

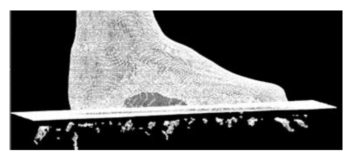
Figure 5. Extraction of the measurement target.

First, the acquired 3D data were loaded and a vertex selection tool was used to select only the rough part of the legs, as shown in Figure 5(a). Next, the selection was inverted and the vertices were deleted to obtain Figure 5(b). Finally, because the 3D model acquired by the Structure Sensor was represented by a set of triangular polygons, Figure 6 was obtained by selecting the triangular polygons by face selection, deleting them, and then displaying the vertices.

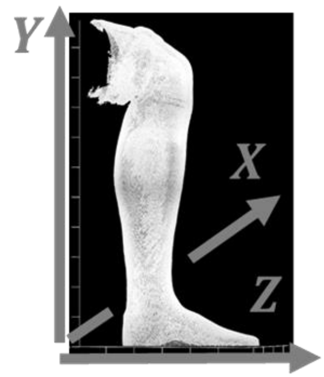
B. Removal of the subfloor

Next, we describe the method of removing the part below the floor surface. If we do this manually, we end up removing the point cloud of the measurement target area near the floor. Therefore, in this study, the floor surface is acquired and removed using a plane-detection algorithm.

Figure 6. Extraction of the measurement target.



(a) Noise under the floor



(b) After deletion

Figure 7. Removal of subfloor.

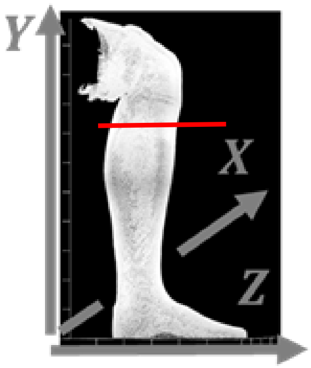
This algorithm is designed to detect the largest plane in the point cloud, such that the side of the leg in Figure 6 is not detected. In addition, during the process of creating a 3D model with the Structure Sensor, the floor surface is generated twice, and, as shown in Figure 7(a), a noise point cloud may be generated in the area below the floor surface. Therefore, when detecting the floor surface, the coordinates of the floor surface should be obtained. Using the obtained coordinates of the floor surface, only the area above the coordinates is extracted, and the coordinates of the extracted point group are shifted by the coordinates of the floor surface, such that the Y-coordinate of the bottom of the leg becomes zero. The processing results are shown in Figure 7(b). By resetting the coordinates in this way, it is possible to measure the circumference at the specified height of the leg.

III. Circumference-Measurement Method That Takes Internal Noise Into Account

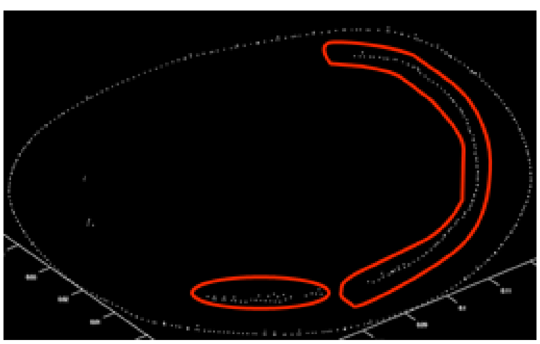
The 3D model acquired and constructed by the Structure Sensor may have internal noise. Therefore, it is necessary to calculate the circumference taking the internal noise into account. For this reason, we used the cross-sectional view obtained by slicing the point cloud for processing.

A. Extraction of the cross-sectional view

The cross-sectional view of the measurement location was extracted from the point cloud data in Section 2. Figure 8(b) shows a cross-sectional view of the red line shown in Figure 8(a). The Kd tree-based search algorithm in MATLAB was used to extract the cross-sections. In this way, a cross-sectional view can be obtained from a 3D point cloud by slicing it at a specified height, which can then be processed in 2D.



(a) Target point cloud

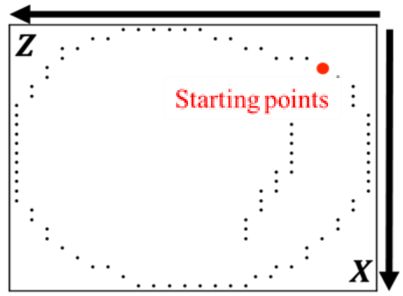


(b) Cross-sectional view
Figure 8. Extraction of cross-sectional view.

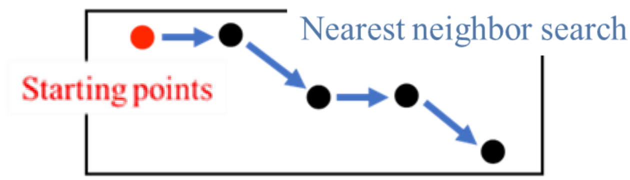
B. Measurement of the circumference using the cross-sectional view

A noise point cloud is generated in the red circle shown in Figure 8(b). Therefore, it is necessary to measure the circumference using only external points, excluding internal noise points in the cross-section. Therefore, we used a nearest-neighbor search to connect and extract only the external points. We used the nearest-neighbor search algorithm using the Euclidean distance in MATLAB.

We defined an arbitrary external point, as shown in Figure 9(a), and set it as the starting point. From the starting point, neighboring points were connected by the nearest-neighbor search, as shown in Figure 9(b). The distance between the two connected points was obtained and summed. By repeating this process until it returns to the starting point, only the external points were extracted and the circumference of the cross-section was calculated by summing the distances between points.



(a) Cross-section and starting point.



(b) Nearest-neighbor search
Figure 9. Conceptual diagram of the process.

IV. Accuracy Verification

In this section, we verify the accuracy of the proposed method. The heights of two points on the legs of two healthy subjects were measured using our proposed method and using a measuring tape. The measured heights were 15 and 28 cm from the floor, as shown in Figure 10. The subject's posture was upright and shooting was performed indoors. Measurements with a measuring tape were taken for each shot. The average circumference value obtained using our method was compared with that using the measuring tape.

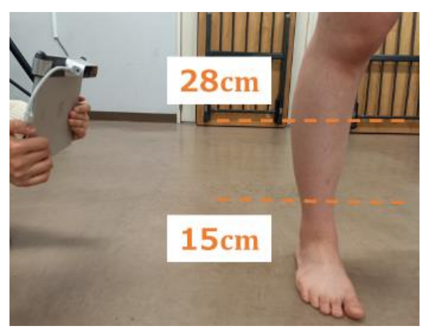
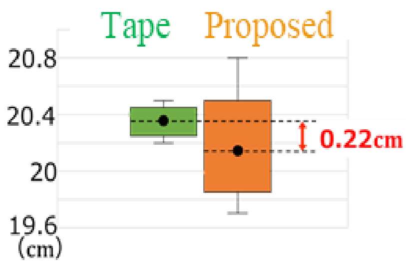
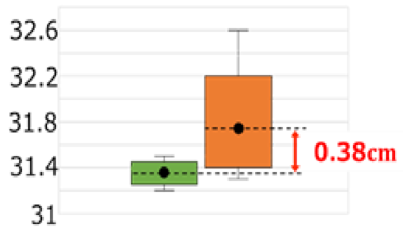


Figure 10. Measurement points and images taken by the Structure Sensor.

A. Experiments and Results

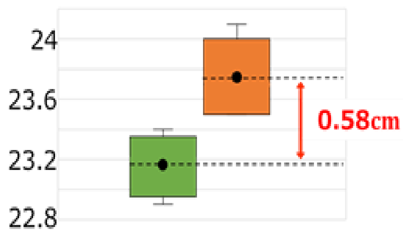


(a) 15cm

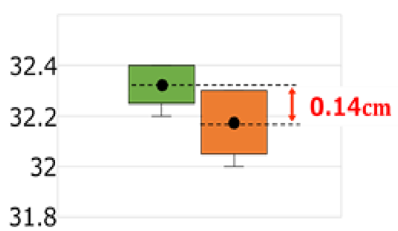


(b) 28cm

Figure 11. Results for Subject A.



(a) 15cm



(b) 28cm

Figure 12. Results for Subject B.

The experimental results for the two subjects are shown in Figures 11 and 12. The green boxplots show the measurement results obtained using a tape measure, and the orange boxplots show the results of our proposed method. The black circles are the average values. The difference between the values estimated with the proposed method and those obtained using the measuring tape was generally less than 0.5 cm, which satisfies clinical accuracy requirements. Nevertheless, future work is needed to further improve the accuracy of this method.

V. Conclusion

We proposed a method for measuring the circumference of legs using a 3D camera, and applied this method to two healthy subjects. Images of the legs were extracted from the 3D model acquired using a Structure Sensor. The cross-sectional view was then extracted by slicing the point cloud at the specified height of the leg. The circumference was calculated using the extracted cross-sections.

The proposed method achieved the accuracy required in the medical field. Future work will include reducing the variability and measuring the leg circumference of patients with edema. Furthermore, other edema symptoms, such as skin discoloration and tightness, will be evaluated in future work to achieve a practical edema evaluation system.

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