A Projection Mapping System onto a Human Body for Medical Applications

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Abstract

In breast reconstructive surgery where patient's abdominal fat and blood vessels are transplanted to the breast, it is very important to identify the course of the blood vessels inside the abdomen. In this paper, we propose a system for projecting blood vessels extracted from computer tomography angiography (CTA) on a patient's abdominal surface to support the breast reconstructive surgery. The proposed system detects the position and orientation of a projector automatically using an image captured by a camera mounted with the projector and is able to project the exact course of the blood vessels onto an abdominal skin from an arbitrary direction. An experiment using an abdominal model fabricated from patient's CTA data with a 3D printer demonstrates the usefulness of the proposed system.

CCS Concepts

• ***Human-centered computing*** → *Mixed/augmented reality;*

1. Introduction

In abdominal free flap breast reconstruction, it is required to identify and locate the blood vessels nourishing the abdominal fat. As a first attempt, Sotsuka et al. projected the blood vessels extracted from CTA data onto a patient's abdominal body with a projector fixed to the direction of the sagittal axis and confirmed the usefulness of the projection mapping approach [S*14]. Later, Hummelink et al. developed a projection method that does not fix the position of the projector [H*16]. They used four markers placed on a patient's body to align the projected image with patient's body, but the method has a position shifting problem when projected from an oblique direction.

In this paper, we propose a projection mapping system, able to project the image onto a patient's abdominal surface without any markers. The proposed system uses the umbilicus position and the outline of the body to align the patient's CTA data with patient's body. The proposed system always projects the blood vessels at the predefined position where the blood vessels are observed from the sagittal axis, even when the projected direction changes to oblique direction. The projection invariant to the pose of the project is important because the view of the doctor is the sagittal direction in surgery.

2. Proposed system

2.1. Process flow

The process flow of the proposed system is shown in Figure 1. The proposed system acquires the position and orientation of a projector using a camera attached to the projector (see Figure 2). (1) First, the system estimates the position and orientation of the camera in the umbilicus coordinates (see Figure 2) using a captured image and patient's CTA volume data. (2) The position and orientation of

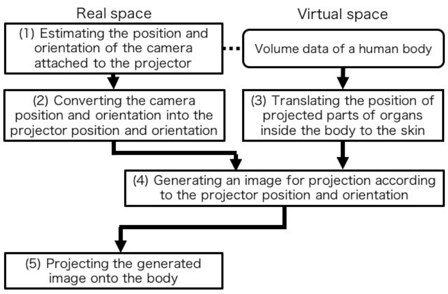

Figure 1: *Process flow of the proposed system*

the camera are converted into those of the projector. A conversion matrix consisting of rotation and translation matrices is obtained in advance employing a camera-projector calibration method.

In virtual space, the blood vessels nourishing the abdominal fat, the umbilicus, skin, and any parts of organs we want to project are segmented in advance from patient's CTA volume data. (3) The Blood vessels and parts of organs inside the body are translated to the skin in the direction of the sagittal axis. This process makes it possible to project the blood vessels and parts of organs at the predefined position even when the projected direction changes to oblique direction. (4) An image for projection is generated by using a splatting algorithm that quickly calculates a volume-rendered image. The viewpoint and view direction of the rendered image are set to the position and orientation of the projector, respectively. (5) Finally, the rendered image is projected onto the patient's body.

2.2. Estimation of camera's position and orientation

The basic idea to obtain the position and orientation of the camera is to match the outlines of the abdominal body in a captured image and a volume-rendered image. That is, the problem results in find-

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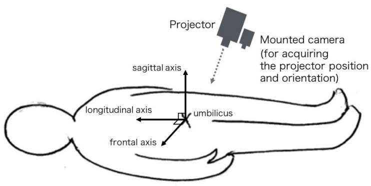

Figure 2: *Camera-Projector system*

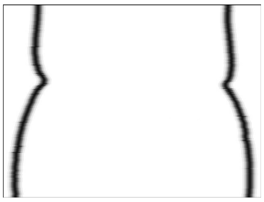

Figure 3: *Outline image of an abdominal body*

Figure 4: *Experimental setting for projection mapping using an abdominal model*

ing the viewpoint and view direction which give the same abdominal body outline when rendering CTA volume data in virtual space. We need to adjust six parameters to obtain the viewpoint and view direction, but by using the umbilicus position in a captured image, which is easily detected from the image, we can reduce the number of parameters to four [K*17]: three rotation angles and one of the three components of translation in conversion of the umbilicus coordinates to the camera coordinates.

To find the optimal four parameters concerning the viewpoint and view direction, we employ a method which combines a genetic algorithm (GA) and a hill climbing method (HC), where GA gives an approximate solution and HC refines the solution. The combination method avoids falling into a local minimum solution and gives a practically sufficient solution. The optimization problem to find the viewpoint and view direction is defined by

$$\textit{minimize} \;\; \frac{1}{N_w N_h} \sum_{v=0}^{N_h-1} \sum_{u=0}^{N_w-1} \left(c(u,v) - g(u,v)\right)^4,$$

where $c(u,v)$ and $g(u,v)$ are the intensities of outline images of an abdominal body (see Figure 3) in a captured image and a volume-rendered image, respectively. To generate the outline image, we employ several image filters such as skin color extraction, boundary extraction and Gaussian filters.

2.3. Translation of blood vessel voxels to the skin

Blood vessels should be projected onto patient's abdominal body at the predefined position where the blood vessels are observed from the direction of the sagittal axis. If blood vessels and other parts of organs inside the body are rendered from oblique direction and projected from the oblique direction, the projected position shifts from the predefined position (see Figure 5 (a)).

To solve this problem, the proposed system translates the voxels of blood vessels and other parts of organs inside the body toward the skin along the sagittal axis in advance of rendering. By this process blood vessels are always projected at the predefined position onto a patient's abdominal body even when the projected direction changes to oblique direction (see Figure 5 (b)).

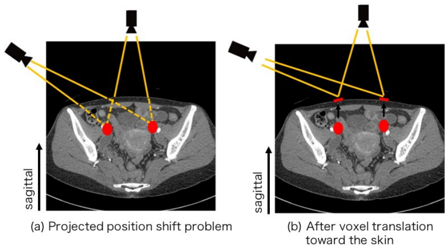

Figure 5: *Solution for the projected position shift problem*

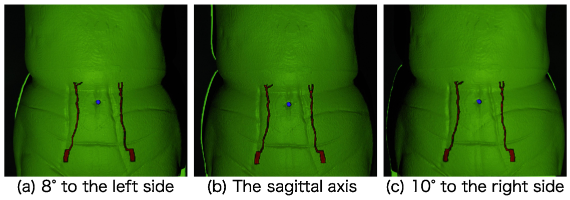

Figure 6: *Projection mapping from different directions*

3. Experiments

We evaluated the proposed system using a scale 1/2.5 abdominal model fabricated from patient's CTA volume data with a 3D printer (see Figure 4). The proposed system consists of a LED portable projector (AddTron Technology QUMI Q6) and an open platform camera (OLYMPUS AIR A01). These devices were mounted on the same platform (on the right side). A digital SLR camera on the left side was used for observing the results of the projection mapping.

Figure 6 shows the results of the projection mapping from three different directions: (a) 8° to the left, (b) the sagittal axis, and (c) 10° to the right. The blood vessels were projected in red. The umbilicus and the skin were also projected in blue and green to confirm the validity of the position and orientation of the projector acquired by our system. To evaluate the accuracy of our projection mapping, we calculated the Intersection-over-Union (IoU) of two regions: the skin of the abdominal model and the projected skin region in green. The IoUs of Figure 6 (a), (b), and (c) are 96.3%, 95.7%, and 91.2%, respectively. Comparing the results projected from different directions, as shown in Figure 6, it can be seen that the blood vessels are always projected at the same position on the abdominal surface in our system.

4. Conclusions

We proposed a projection mapping system for a medical application. The proposed system detects the projector position and orientation without any markers and always projects objects of interest inside the body at the same position on the human body even when the projected direction changes. Future work includes building a practical system based on the prototype system.

References

[H*16] HUMMELINK S., ET AL.: Displaying inguinal lymph nodes before transplantation in a deep inferior epigastric perforator flap breast reconstruction using an innovative projection method. *Journal of Plastic, Reconstructive & Aesthetic Surgery 69*, 3 (2016), 376–380. 1

[K*17] KUBO K., ET AL.: The development of human body projection mapping system for image guided surgery. *Proceedings of the Meeting of Federation of Imaging Societies 63* (2017), 1–6. 2

[S*14] SOTSUKA Y., ET AL.: Image overlay of deep inferior epigastric artery in breast reconstruction. *Plastic and Reconstructive Surgery Global Open 2*, 10 (2014). 1