G-023

Development of A Multimodal 3D Breast Ultrasound

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***Abstract*—Mammography and breast ultrasound are the two most common screening tests for breast cancer. Mammography takes multiple X-rays that are combined to create a single 3D image of the breast. Breast ultrasound, on the other hand, applies ultrasound waves to the surface of the breast to create a profile image of the breast's interior. This study attempts to generate 3D breast ultrasound volumetric data by combining ultrasound images obtained from a series of Breast ultrasound scans. To generate this data, a rotary encoder was installed on the Breast ultrasound and information of scanning distance is recorded for each ultrasound image. As a result of the encoder validation, an RMSE of 1.03 mm was obtained when running on a 100 mm plane. On the other hand, when gel was applied to that plane, the RMSE increased to 6.95 mm. This indicates that the rubber wheel slipped during scanning and should be pressed more into the plane during scanning. Observation using the breast ultrasound phantom shows that the generated lumps can be successfully observed using the generated 3D breast ultrasound volumetric data.**

Keywords—3D breast ultrasound, volumetric data, breast cancer, 3D slicer

I. INTRODUCTION

Breast cancer is one of the most diagnosed cancers. Recent studies reveal that 685,000 women have died from breast cancer in 2020 [1]. The simplest and most cost-effective way to reduce mortality rather than treatment of advanced disease is early detection. Therefore, reliable screening technology is required. Some of the popular technologies used include mammography and breast ultrasonography. Breast ultrasonography is not used as a routine screening for breast cancer, but it is useful for viewing lumps and other breast changes that are not visible on a mammogram. It sees dense breast tissue that is difficult to see on mammography. It can also be used to follow up on suspicious areas seen in mammography.

One of the drawbacks of conventional breast ultrasound, a device used to perform breast sonography, is that it provides only a profile image of the breast, lacking anatomical and orientation information. The clinician must imagine the 3D structure of the breast from a series of scanned ultrasound images. However, this work requires a longer examination time. In addition, it is difficult to accurately capture the 3D structure of the breast.

Recently, a technique to generate 3D ultrasound volumetric data using conventional breast ultrasound has attracted much attention. To generate this data, it is necessary to acquire posture information of the breast ultrasound probe during scanning. This probe must be tracked by a sophisticated motion capture system, but it is not practical to install a large motion capture system in a medical setting. An alternative to motion capture is the development of smaller and easier to install sensors.

This study proposes a method to generate volumetric data of breast ultrasound by installing rotary encoders on the probe to measure the distance traveled by the probe. From these data, we propose a method to generate volumetric data by interpolating a series of scanned ultrasound profile images.

II. RELATED WORKS

Many studies have been conducted to develop a 3D breast ultrasound system; a system based on ultrasound probe that can provide volumetric data. Kim et al. (2020) developed a 3D breast ultrasound system using sensors, such as an ultrasonic distance sensor, a gimbal, and an additional IMU to measure probe pose information during scanning [2]. The pose information from these sensors was processed using the open software Plus Toolkit [3], and the series of breast ultrasound images were volumetricized using the 3D Slicer [4]. This system enables 3D scanning within a margin of error of 1.4 mm. However, to achieve stable scanning, the probe must be secured by a kinematic arm. The arm must be designed to flexibly accommodate the position of the part to be scanned, making the system substantially as large as motion capture.

A multimodal system was also developed to measure the shape of the scanned object along with the 3D breast ultrasound volumetric data [5]. The orientation of the probe was tracked by triangulation with three markers, while the shape of the object was measured using a pattern projection method. An error of 0.12 mm was observed between the two modalities. This measurement system is easy to use because it is remotely sensed, but it is difficult to measure due to occlusion.

An attempt at simple 3D breast ultrasound measurement has been proposed using an inertial measurement unit (IMU) to measure the pose of the breast ultrasound probe and a housing to which the probe is attached for stable scanning [6]. This mechanism seems to be very effective. However, the IMU values are not stable and tend to be more unstable, especially during scanning movements.

In summary, there is room for improvement in the posture measurement sensor attached to the ultrasound probe for generating 3D ultrasound volumetric data. Simpler sensors need only be added to the existing probes to facilitate measurement.

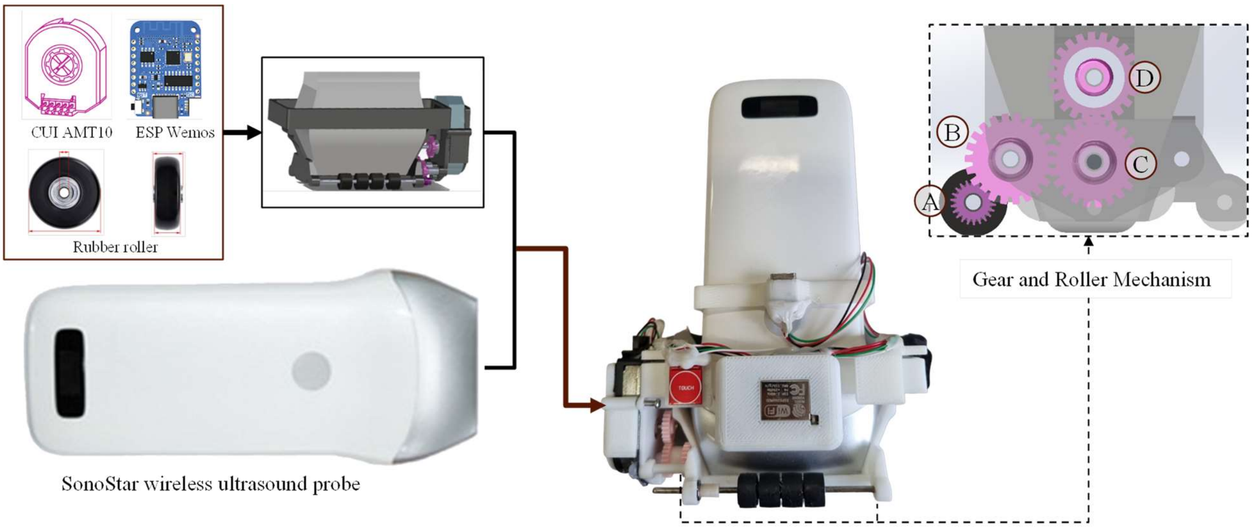

Figure 1. Hardware implementation of 3D breast ultrasound probe

III. METHODS

This study proposes a mechanism that uses a rotary encoder to scan distance. We consider that the original 3D shape of the scanned object does not need to be completely restored in order to generate 3D ultrasonic volumetric data. The reason is that the object to be measured is relatively soft, it sinks when the ultrasonic probe touches it, resulting in the shape of the region no longer retaining its original shape.

A. *Hardware Implementation*

Our implementation uses the linear array probe, the SonoStar wireless breast ultrasound probe [7]. This device is capable of observing tissue under the skin at a depth of 4 to 10 cm and a width of 5 cm. Figure 1 shows the rotary encoder, rubber roller for sliding, and microcontroller, with these components mounted on the tip of the probe. Five gears were used to transmit the rotation of the roller to the rotary encoder to calculate the scanning distance.

The scanning distance is determined by multiplying the number of rotary encoder pulses (*EP*) by the circumference length per pulse (*CLPP*).

$$Scanning\ distance = EP \times CLPP \qquad (1)$$

Here, *CLPP* is obtained by dividing the revolution length by the encoder resolution (4,096). As shown in Figure 1, since different gear sizes were employed, the *CLPP* between gears must be converted by the ratio of the number of teeth on both gears. The CLPP of gear Ⓑ from gear Ⓐ can be calculated by

$$CLPP = 4{,}096 \times \frac{Cogs\ Ⓑ}{Cogs\ Ⓐ}\ , \qquad (2)$$

where *Cogs* Ⓐ and Ⓑ represent the number of teeth on gear Ⓐ and Ⓑ, respectively.

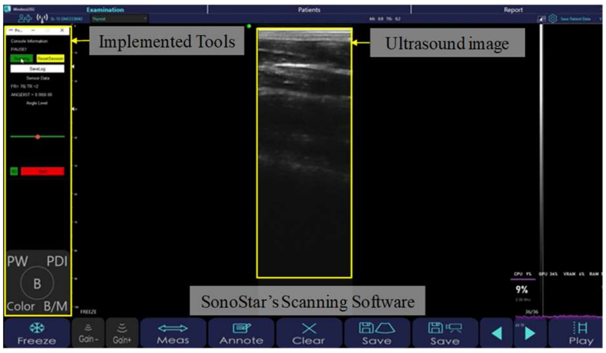

Figure 2. Data acquisition automation tool implemented on top of the original SonoStar software.

Table 1. Meta information of acquired data

Elapsed time (s)	Travel distance (mm)	Image number
0.03	0.1	#1
0.06	0.2	#2
0.09	0.3	#3
⋮	⋮	⋮

B. *Software Implementation*

The software implementation includes data acquisition from the breast ultrasound probe and generation of 3D volumetric data.

a) *Data Acquisition*

Currently, low-cost commercial Breast ultrasound probes are equipped with scanning software for data acquisition without an open API (Application Programming Interface). In this study, we developed software that automatically controls this software with an external code and links the acquired breast ultrasound images to their associated scanning distances in order to seamlessly perform a series of processes from scanning to the generation of 3D volumetric data. Figure 2 shows our implementation of the scanning software. The elapsed

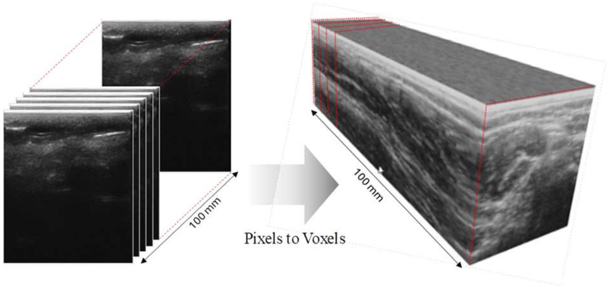

Figure 3. The pixel-to-voxel transformation in this study.

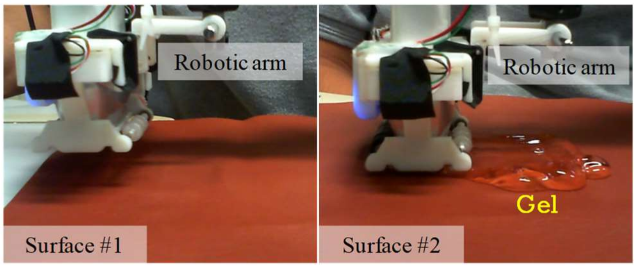

Figure 5. Experiments on surfaces #1 and #2.

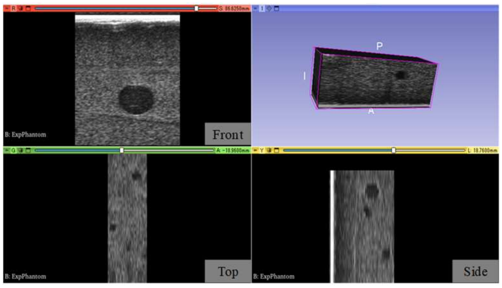

Figure 4. Data visualization in the 3D Slicer software.

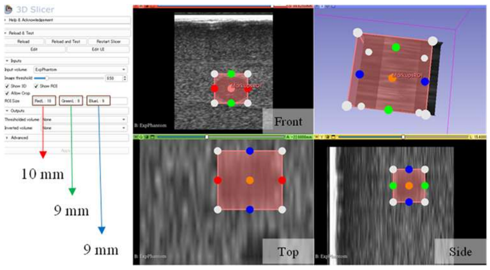

Figure 6. Lump observation from the phantom.

time, distance traveled, and image number are recorded as scanning data (Table 1).

b) 3D Volumetric Data Generation

The 3D volumetric data generation process arranges the scanned images in 3D space according to their displacement distances, as shown in Table 1, and then creates voxels based on each pixel. Figure 3 shows a schematic of the pixel-to-voxel transformation. The conversion to voxels fills in the gaps between the original images and allows slicing along the three axes (x, y, z) at arbitrary locations.

c) Data Visualization

To visualize the generated volumetric data, this study uses 3D Slicer, an open-source software for biomedical image visualization and processing. Figure 4 shows the volume data displayed in 3D Slicer. This data can be viewed in any profile orientation and in the 3D volumetric scene. Basic functions such as distance measurement, segmentation, and color rendering are implemented.

IV. CONCLUDING RESULTS

The prototype device was evaluated for the accuracy of the rotary encoder and the accuracy of the generated 3D ultrasonic volumetric data.

a) The Accuracy of the Encoder

The experiments were conducted on a 100 m long flat surface covered with leather and the same surface coated with gel (hereafter referred to as surface #1 and surface #2). Figure 5 shows the experiments on surfaces #1 and #2. A robotic arm (Dobot Magician) was used for stable sliding of the device. The experimental results show that an RMSE of 1.03 mm was achieved on surface #1. On the other hand, on surface #2, the RMSE increased to 6.95 mm, indicating that the rubber wheel slipped during scanning. Improvement of the wheel is essential to improve the measurement distance with the rotary encoder.

b) The Accuracy of the Generated Volumetric Data

Experiments were performed using a breast ultrasound phantom with multiple spherical lumps. To prevent rubber wheels from slipping, measures were taken to push them more into the surface during scanning. The 10mmx10mmx10mm lump was clearly observed from the generated 3D breast ultrasound volumetric data and its size was measured to be 10mmx9mmx9mm.

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