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Design and Fabrication of Prostrate Ring-scanning Equipment for NIR Diffuse Optical Imaging

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1 Background

Diffuse optical imaging (DOI) providing functional information of tissues has drawn great attention for the last two decades [1]. Near infrared (NIR) DOI systems composed of scanning equipment, opt-electrical measuring module, system control, and data processing and image reconstruction schemes are developed for the screening and diagnosis of breast tumors. Mostly, the scanning equipment belonging to fixed source-and-detector configuration limits computed image resolution to an extent [2-4].

To cope with the issue, flexible ring-scanning mechanism design has been investigated and analyzed in order to obtain the most probable effectiveness and efficiency while retaining acceptable scanning time. Before the detail design of ring-scanning equipment was conducted, finite-element-based image reconstruction schemes were performed to obtain tomographical images through changing source-and-detection arrangement of the ring-scanning mechanism. From the simulation [5], the 2Z3S or 3Z3S configuration was found an apparently better design for the ring-scanning mechanism in terms of both the resolution of reconstructed optical-property images and the scanning time of equipment. Following the previous study, this technical brief demonstrates the design, fabrication and test of the prototype ring-scanning equipment.

2 Methods

Prostrate ring-scanning-based architecture in the developed NIR DOI system is considered for the screening and diagnosis of breast tumors, as shown in Fig. 1 the schematic diagram of the system. The ideas and concepts of design are based on the following consideration:

- comfort: noncontact and human-laid-bed (prostrate) design avoiding subjects' discomfort, and then increasing their willingness to be screened,
- flexibility: adjustable detection range for various breast dimensions, and
- efficiency and effectiveness: multi-point illuminating design to reduce the scanning angle, thereby to speed up the diagnosis.

The circular scanning module is divided into *m* zones, and each zone includes *n* NIR sources and *l* detection fibers. Due to the space limitation and the physical dimension of source- and detection-fiber heads, 36 source- and detection-channels are adopted, and 10^{o} separation between each two heads being are arranged.

Mechanism for radial movement of optical source-and-detector channels

The radial movement of a single optical channel set is functioned as through radial guiding slot and an optical channel bracket. A bracket makes an optical channel set fixed, as shown in Fig. 2. A single optical channel set (Fig. 3) is composed of an illumination fiber or a liquid light guide (LLG) for detection, a light guide unit with two fixers, a linear guideway incorporated with a seat driven by a stepping motor, a link and a bearing. To drive the whole 36 optical source-and-detector channels, Fig. 4 shows the mechanism which mainly includes a rotating disk, a belt tension pulley, a V-belt pulley and a V-belt for the purpose of a radial movement.

Mechanism for circular movement of optical source-and-detector channels

Figure 5 demonstrates the angular-movement mechanism of optical source-and-detector channels, mainly including a stepping motor and a speed-reduction gearbox with bevel gears.

In a radial-movement mode to drive each optical channel bracket, it was realized by the link moving in the guiding slot, where a bearing is mounted at the other end of link to allow the link rotating with the inner race. The rotating disk was driven by a stepper motor and a V-belt set for speed reduction, as shown in Fig. 4.

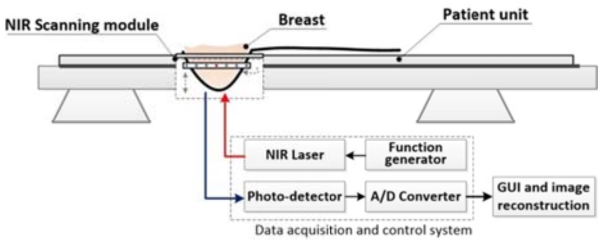

Fig. 1: Illustration of prostrate NIR DOI system.

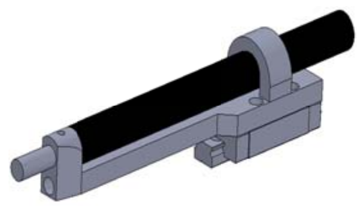

Fig. 2: Schematic of optical channel bracket.

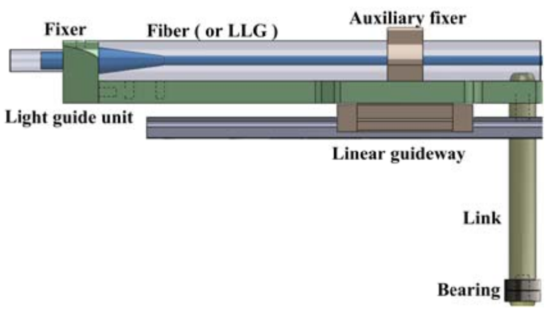

Fig. 3: Schematic of a single optical channel set.

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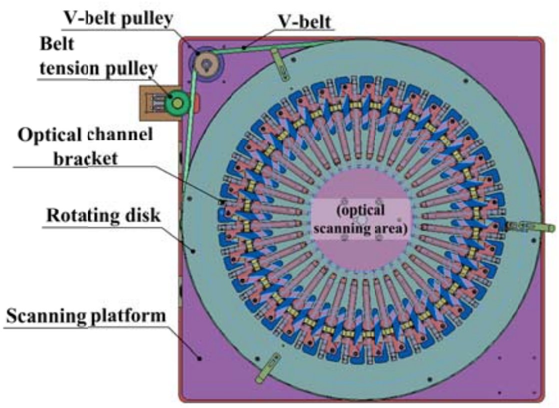

Fig. 4: Schematic of the radial-movement mechanism for optical source-and-detector channels.

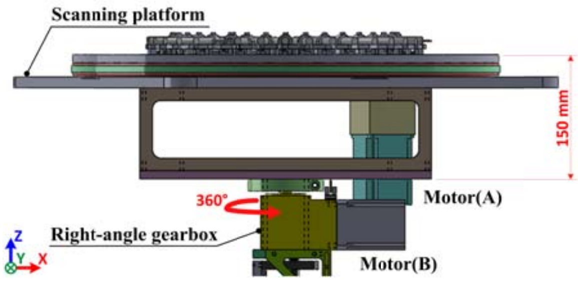

Fig. 5: Illustration of the circular-movement mechanism for optical source-and-detector channels.

In a circular-movement mode to achieve ring scanning, Fig. 5 shows a stepper motor installed beneath the scanning platform connects to a bevel gearbox with a speed reduction ratio 2 for a smooth drive. The ring-scanning angle can be as high as 360° which is dependent on the source-and-detector configuration used; for instance, the scanning angle is 150° for the configuration 2Z3S. Here *Z#S denotes all optical channels set into * zones, and # illumination channels in a single zone. Therefore, six illumination channels and thirty detection channels totally are in the design of configuration 2Z3S associated with thirty-six optical channels.

In this prostrate equipment for NIR diffuse optical imaging, our experimental scenario is designated as below.

(1) As a subject is lying on the bench to make breast suspend among the source-and-detection fiber heads, the optical channels are driven radially and close to the chest wall according to the sensing of optical displacement sensors and light switches.
(2) The ring-scanning module is driven counterclockwise, rotating an interval of 30° for configuration 2Z3S. As soon as the out-emitted NIR radiance is acquired for a complete 150° circular movement, the module stops motion.
(3) The module returns to the starting point clockwise and back to the maximum radial position as the ring-scanning module completes a full scanning.

3 Results

Based on the synthesized design with acceptable scanning time and simulated imaging quality [5], the prototype equipment was machined and assembled, as shown in Fig. 6. The experiments to acquire NIR data and reconstruct images for verification will be performed in the near future. To illustrate probable image reconstruction through the proposed prostrate ring- scanning equipment, a computational case study was synthesized. Figure 7 illustrates two sets of reconstructed μ_a and μ_s' images for the design of configuration 2Z3S associated with 18 and 36 optical channels, respectively. In the simulation case, a 10-mm-diameter tumor in a 100-mm-diameter background tissue is assumed. The original cross-section image was obtained with slicing a 3D breast MRI from Taipei Medical University Hospital.

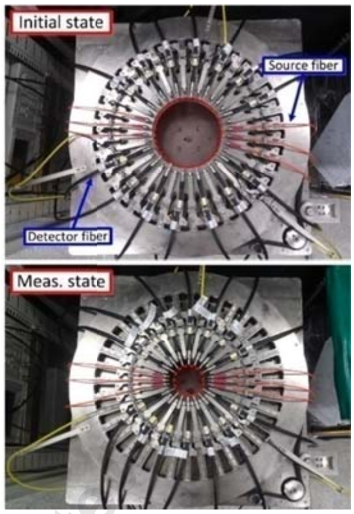

Fig.6: Demonstration of prototype instrument (upper) initial state, (lower) measuring state.

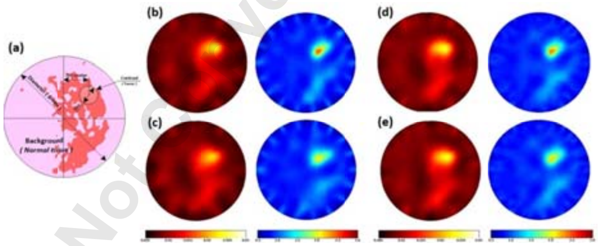

Fig. 7: (a) Synthesized phantom with an inclusion added, and reconstructed μ_a and μ_s' images of synthesized cases for a comparison between fixed-channel ((b) 18 and (d) 36 optical channels) and the proposed 2Z3S designs ((c) 18 and (e) 36 optical channels).

4 Interpretation

The proposed *Z#S design is rather cost-effective than the fixed optical-channel one. As to the performance of image reconstruction, Fig. 7(c) and 7(e) are still competitive to their counter parts, Fig. 7(b) and 7(d), respectively.

Acknowledgement

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