DEVELOPMENT OF FLEXIBLE 2D ULTRASOUND ARRAYS FOR SCOLIOSIS ASSESSMENT

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Abstract— **Conventional way of assessing scoliosis requires taking X-ray radiograph on the coronal plane of the spine. Rapid radiograph examinations on scoliosis patients could produce radiation hazards and increase the risk of cancer. Recently, it has been shown that ultrasound imaging could produce reliable Cobb's angle measurement for scoliosis assessments.**

However, this method requires moving the ultrasound probe manually by physician's hand and could produce error if subjects moved during the imaging process. More importantly, it is very difficult to take images when subjects are wearing back braces.

This study has aimed to overcome the above issues by developing a flexible ultrasound transducer arrays which could stay on subjects' back during the examination. 4mm diameter piezoelectric transducer elements were soldered onto copper flexible Printed Computer Board (PCB). The transducer surface was then emerged into soft silicone gel to eliminate possible air gaps and provide comfortable cushioning between transducer and the subject's back. Accelerometers and electromagnetic spatial sensors were explored to measure the elements' location and orientation.

The Preliminary results showed that the structure of the spinous process could be identified with the flexible transducer array by comparing A-mode signals with B-mode images taken with conventional ultrasound probe.

It was also suggested that the larger angular coverage of the flexible transducer array could be helpful for studying the orientation of reflecting surface. This could be done by finding the angle of reflection of the echoes by capturing signals with nearby elements during single element stimulation.

Keywords— **scoliosis, flexible 2D ultrasound arrays, spine imaging, coronal plane.**

I. INTRODUCTION

Scoliosis is a spine deformity disease which results in a lateral curvature of the spine on the coronal plane. It is often coupled with vertebral rotation of the spine as they are considered in most cases idiopathic [1]. In Hong Kong, there are around 3.1% of children suffering from scoliosis [2]. Scoliosis can be treated by surgery, physical therapy or by wearing TLOS (Thoraco-Lumbo-Sacral-Orthosis) brace and etc. [1]. To provide diagnosis for this disease, the gold standard is to measure the Cobb's angle of patient's spine on the coronal plane [3]. This is usually done by X-ray examinations on the thoracic plus abdominal region of the body. Once scoliosis is detected, regular and rapid X-ray assessments on patients might be required to monitor curvature progression, treatment outcomes and especially to ensure correct fitting of the TLOS brace. Rapid assessments using X-ray could lead to radiation hazards and increase in risk of cancer [4]. Although a recent imaging device (EOS imaging) has been shown to reduce X-ray doses to patient when performing spine imaging examinations [5], it is still more desirable to minimize or eliminate the radiation hazard in scoliosis assessments.

It has recently been demonstrated that 3D ultrasound imaging is feasible imaging method for the assessment of scoliosis [6] [7]. This new imaging system has eliminated the radiation hazards on spine imaging as ultrasound imaging is non-ionizing. This imaging system requires moving the ultrasound probe vertically down the subject's back by physician's hand while the ultrasound probe is installed with an electromagnetic spatial and orientation sensing device [8]. The location of the spinous process and the transverse process were then identified from the ultrasound images for calculation of the Cobb's angle. However, the scanning process normally takes a few minutes and the major limitation of this is the possible error caused by patients' movements during the scanning processes. It is also very difficult to perform the imaging on subjects' back when subjects are wearing a TLOS brace. As the brace will have to be opened at the back for ultrasound scanning, this could reduce the brace pressure on the body and hence affect the brace performance.

In order to overcome these issues, we proposed to develop a flexible 2D ultrasound transducer array which can fit and stick onto the back of the subject during ultrasound scanning. This flexible array will potentially provide an ultrasound imaging method on the spine where no manual or mechanical movements of the probe will be needed. More importantly, it can be used when brace are worn normally by subjects, which helps providing accurate examination on the brace performance.

Another advantage of this flexible ultrasound transducer array is the increase in angular coverage on the body surface [9]. This can increase the collection of acoustic information by collecting reflected acoustic signals with the adjacent elements.

This can potentially increase the signal contrast and can be used for determining the orientation of the reflecting surface i.e. the spine surface at specific region.

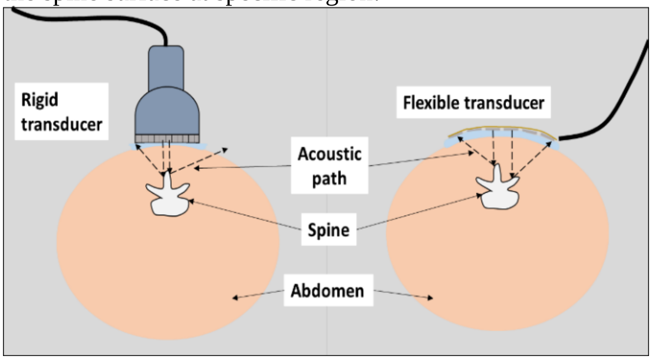

Fig. 1 Illustration of increase in angular coverage using flexible ultrasound transducer array on a curved body surface compare to conformal rigid ultrasound transducer array [9].

Different spatial sensors and/or bending sensors will be explored to find an optimized solution for this imaging method.

II. Transducer array design

A. Design requirements

The two most important requirements of the transducer arrays design are to be flexible and sticky enough to stay on the subject's back during the examinations. It should also preferably cover the whole back from the first thoracic vertebrate (T1) to the fifth and also last lumbar vertebrate (L5), although smaller prototypes will be made at this stage.

Another important requirement would be to minimize the thickness of the transducer arrays in order to fit in the narrow gap between the TLOS brace and the back of the subject.

B. Arrays components

a) Piezoelectric transducer probes

Piezoelectric (PZT) material were used in this transducer design although other type of ultrasound generating method such as laser-generated ultrasound [10] could be a possible alternative.

The transducer probes used in this design have 4mm diameter of transmission surface and probe thickness of 5mm. Centre of transmission frequency is 5.18MHz.

As we aimed to design a transducer which can cover the full length of the back of the spine, using small conventional ultrasound elements would greatly increase the total number of elements and the complexity of the circuitry. Hence relatively larger transducer elements were used in this design to reduce the amount of elements needed. However, this would also reduce the image resolution due to wider spacing between probes.

b) Flexible Printed Circuit Board (PCB)

The PCB is made of thin copper sheet coated with a plastic layer. Total thickness of the flexible PCB is 0.2mm. The distance between centers of piezoelectric probes when soldered is 6mm. 6x6 probes were soldered onto each flexible PCB sheet.

c) Spatial and orientation sensors

In order to determine the position or more importantly the relative position and orientation of each PZT probes during the imaging process, different spatial sensors were explored. Accelerometers were proposed to be used due to their few advantages; small and no limitation to the maximum amount of sensor. Although they can only provide orientation information, combining them with electromagnetic spatial sensing device could provide enough information for the imaging process.

d) Solid gel pads

During scoliosis assessments, subjects can be standing up, leaning forward or in other postures. Hence it is important that the ultrasound transducers can attach on subjects' back stably using solid gel pads. The gel pads must also have low acoustic attenuation and similar acoustic impedance as body tissue to maximize the transmission of acoustic energy from the transducers to the body.

As any small air gap between transducer and the skin will produce strong reflection of ultrasound wave due to impedance mismatch, the gel pads should ideally be soft enough to fit perfectly onto the irregular surface of the back. Soft gel pads can also provide cushioning between the rigid transducer and subjects' skin especially when brace were worn on top of the transducers.

Silicone gel were used due to its flexibility and stability over long period of time.

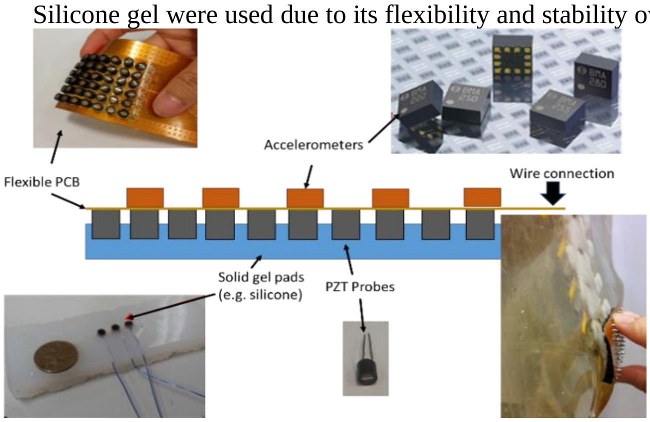

Fig. 2 Figure illustrated the design of flexible ultrasound array. The top left and bottom right corner of this figure has shown the flexibility of the first prototype

III. METHOD AND RESULTS

The first goal is to provide enough acoustic information with the flexible ultrasound array to accurately determine the Cobb's angle. Bony features such as the spinous process and the transverse process were attempted to be identified using transducers probes in single line array. A full length spine phantom from the C1 vertebrate to the coccyx embedded into silicone gel was used in this study. A B-mode ultrasound image was taken using 128 elements transducer array on the T2 vertebrate where the structure of the spinous process could be observed clearly on the image, see Fig. 3.

Flexible transducer array were placed on the same location where elements were stimulated separately on a single line at the T2 vertebrate. By comparing with the B-mode image obtained before, the reflecting bony structure corresponding to each echo were identified manually. Using this method, the location of the bony structure could be identified along the whole spine for Cobb's angle examination.

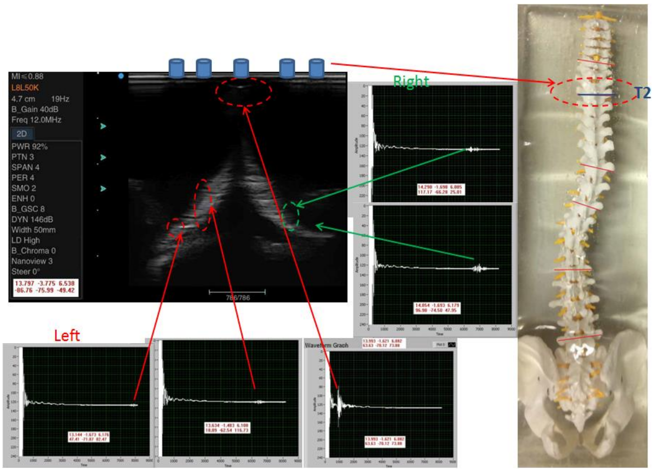

Fig. 3 B-mode image of T2 vertebrae, and the corresponding A-mode signals measured on the same location with flexible ultrasound transducer.

IV. Discussion and conclusion

This preliminary study demonstrated that the design of this ultrasound transducer array could provide flexible bending on the transmission surface. The surface of the transducer could fit onto surface with complex geometry given with its flexibility. Emerging the transducer surface into silicone gel with sticky surface could ensure secure connection between the arrays and the back of the subject and eliminating possible air gaps created during subject's movements.

Although the separations between probes of this flexible ultrasound transducer array are relatively large compare to conventional ultrasound array, it has been shown that the echoes obtained by stimulating individual element separately could be used to identify the spinous structure by comparing the A-mode signal with B-mode images taken with conventional ultrasound imaging transducer.

It is undoubtedly important to explore on possible spatial and orientation sensing device as determination of probes location would be very important for identifying the image location. Capturing echoes with adjacent probes after single element stimulation could also enhance the signal magnitude and help identifying the orientation of the reflecting surface which could be studied on the future.

Acknowledgment

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Conflict of Interest

The authors declare that they have no conflict of interest.

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