Pin-art ultrasonic transducer for non-destructive examination

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Abstract. The novel pin-art ultrasonic transducer brings connivence, efficiency and flexibility for high-quality non-destructive detection. Half-flexible structure offers a promising solution to the challenge of current flexible ultrasonic transducers-flexibility and identifying components. The device allows for simple and efficient detecting of almost all canonical geometries and complex shapes. In addition, its structural convenience offers opportunities for cheap repair and muti-task functionality. The pin-art ultrasonic transducer holds great implications for ultrasonic detection through complex surfaces.

Keywords: Pin-art ultrasonic transducer, ultrasonic detection, non-destructive detection.

1. Introduction

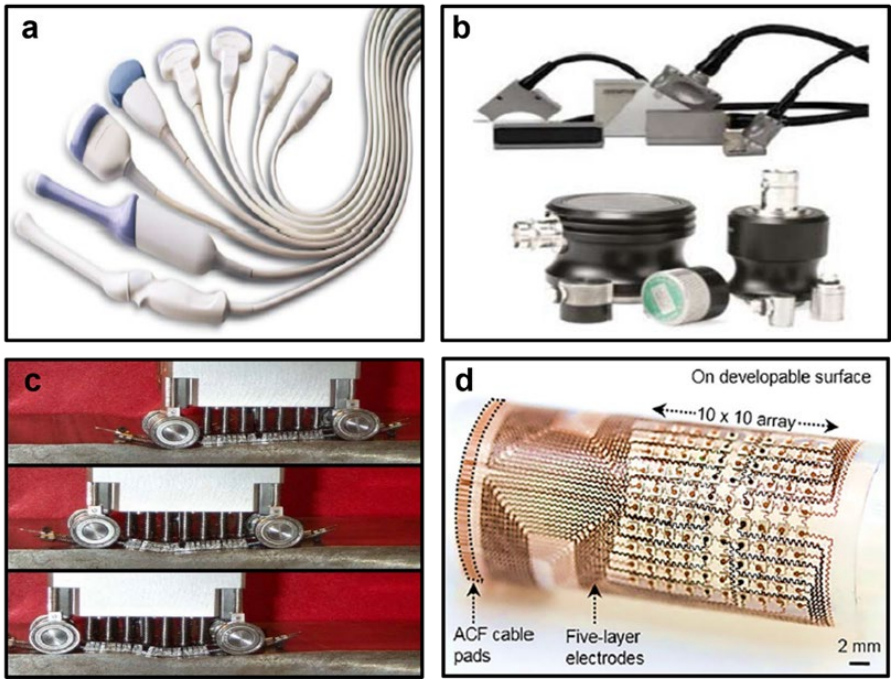


Figure 1. (a) Pictures of common fix-shape biomedical ultrasonic transducer (GE Healthcare products, Ultrasound Transducer), (b) regular industrial ultrasonic transducer (Plympus, Contact Transducer) (c) ultrasonic devices with flexible phased array [7], and (d) ultrasonic devices with flexible substrate [8].

Ultrasound transducers have been demonstrated to be critical in biomedical and industrial applications [1-3]. In biomedical engineering, imaging based on ultrasound devices offers important reference data for physicians [4]. In industry, portable ultrasound devices have significantly contributed to nondestructive inspections. However, because of restriction of structural flexibility, when measuring irregular surface, a fixed shape of transducer can cause a large non-contact area which seriously interferes with the wave transmission, leading flaw image [5, 6]. As shown in Figure 1 (a) and (b), to minimize the issue, varied transducers with non-planar shape are designed to detect corresponding-shape specimen. However, in order to detect specimens with irregular surfaces, multiple transducers should be used, and image quality is not guaranteed. In recent years, as shown in Figure 1 (c) and (d), novel ultrasound devices have been developed that aim to overcome the constraint of flexibility by utilizing a stretchable substrate or a flexible phased array [7, 8]. However,

flexible ultrasound transducers have limitations on locating each transducer element without assisting complicated compensation algorithm, optical fiber or 3D camera [6, 9]. Difficulty locating each ultrasonic transducer element disturbs and complicates the imaging process.

2. Proposed idea

We recognize that the primary challenges with flexible array transducers are identifying components and decreasing the coupling layer, and hence built a matrix array transducer inspired by toys for irregular surfaces (Fig.3.a and b). As seen in Figure 3.c.d.e, the device adhered to the surface by altering the vertical coordination of each pin transducer. The device's construction enables attachment to both developed and underdeveloped surfaces. Due to the constant horizontal coordination of the transducer elements, the location variation of each transducer element may be monitored using a replacement detector within. By receiving ultrasonic reflection and assistance of imaging-algorithm, the device can collect the 3D model of the surface and create high quality 3D image.

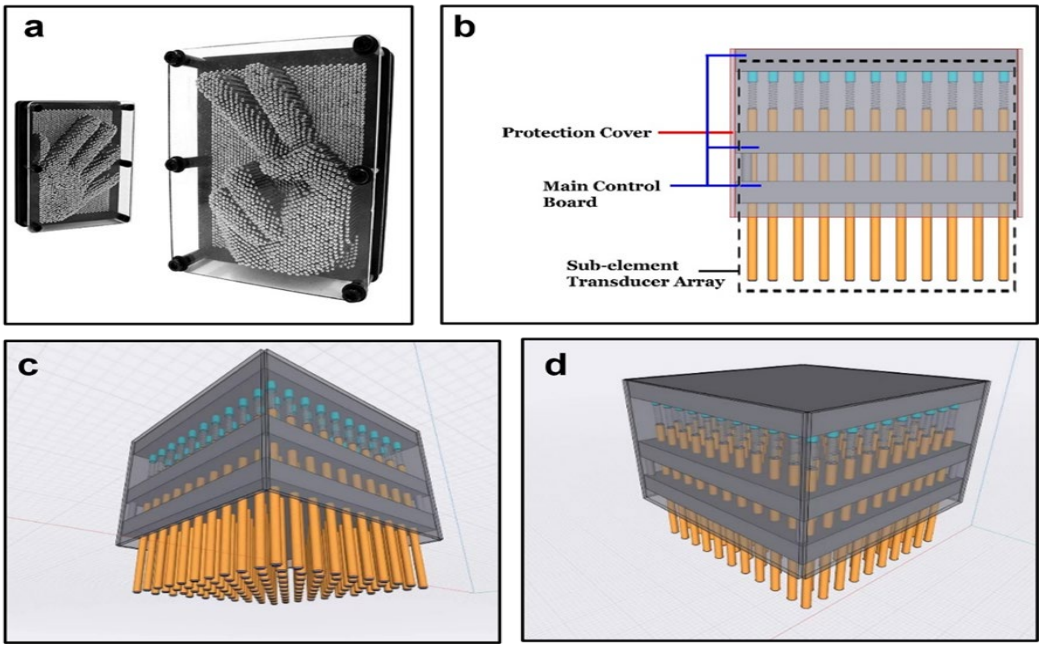


Figure 2. (a) The inspiration of the device--A regular pin-art toy. (b) Side schematic view of three main components of the device. (c) and (d) 3D schematic view of illustration of the pin-art ultrasonic device.

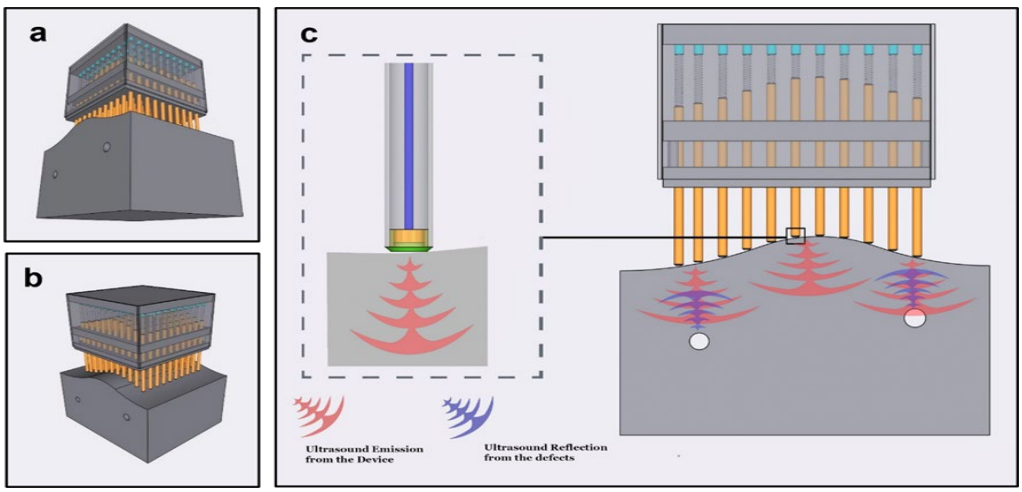


Figure 3. (a) and (b) Simulation of detecting specimens with irregular surface. (c) The schematic diagram of ultrasound waves generation and detection during detection.

3. Device design and component selection

The schematic structure of the device is depicted in Figure 3. The half-rigid structure accommodates the complicated surface, with each element having a limited spring. As illustrated in Fig 3.b.c, to prevent horizontal displacement which can seriously interrupt collected 3D model, all sub-element transducers are rigidly placed into the main control board. As illustrated in Fig.4.b, each element has an upper and a lower probe. When the lower probes are connected to the specimen surface, the higher probes assess vertical coordination and transfer the data to the computer, which generates an imaging compensation algorithm. Each element probe in the array is addressable and disconnected independently. Conductive access to external power supplies is provided by the wire bonded to the Cu tube.

The schematic diagram of the element probe is shown in Figure 3 and 4. The piezoelectric transducers are arranged in 16 × 16 array, and each transducer has an independent sub-element transducer to measure vertical coordination. For fabricating each (sub) element transducer, the piezoelectrical material (PZT) is lapped to 550 μm for the working frequency of 3.5 MHz. Conductive matching layer (Ag-Epoxy composites) and copper tube with 1 mm diameter is attached to the piezoelectric material as the electrode. The conductive backing layer (Esolder 3022) is attached to the piezoelectrical material and connected to a wire [10]. The epoxy resin is used to consolidate the structure integrity. For connection and vertical stretchability, as Fig.4.b shows, two probes are connected by a spring which is attached to the rubber rings on each copper tube.

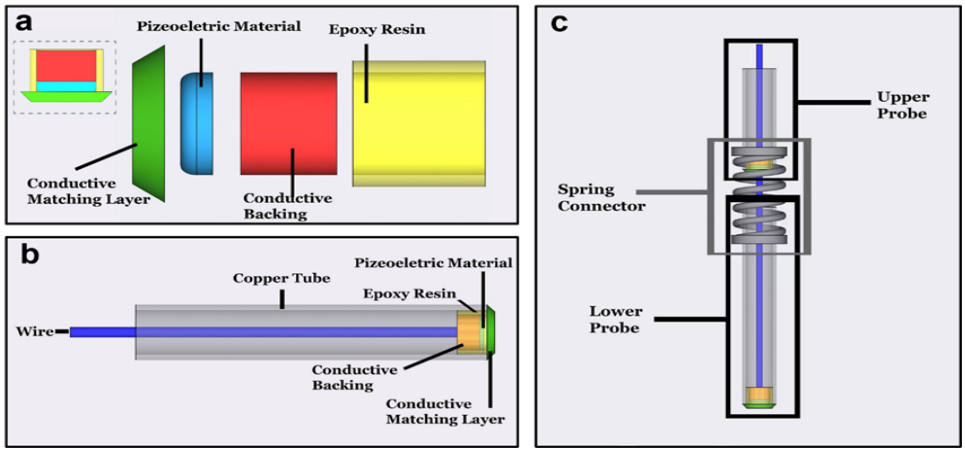


Figure 4. (a) the schematic diagram of a transducer element. (b) The inner structure diagram of pin-art ultrasound transducer and (c). Vertically stretchable sub-element transducer

4. Proposed beamforming

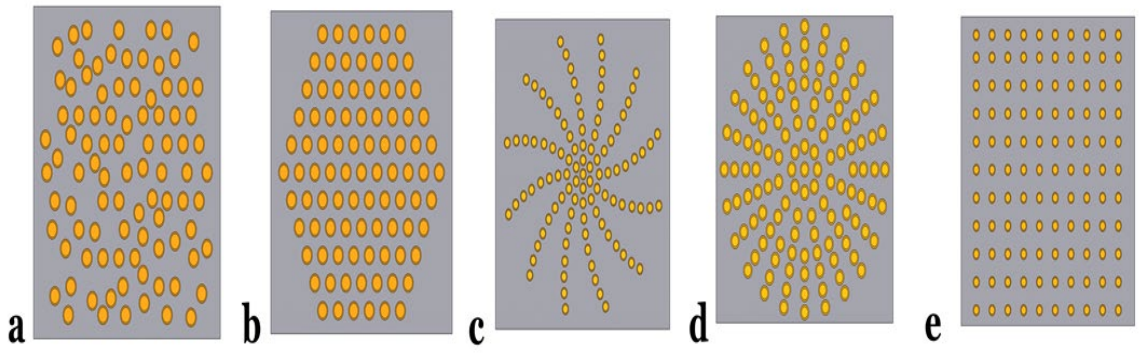


Figure 5. The schematical diagrams of specific element-arranged ultrasound transducer.

Calculating ultrasonic beam field visualizes the ultrasonic energy and yielding image of specimen. The summation of the contributions of individual sources distributed along the surface of the probe

can be assumed to be the model of ultrasound beam filed. Once all contributions have been evaluated, the impulse response is calculated and convoluted with the waveform of the probe. For phased-array probes, each individual contribution is phase shifted in accordance with the time delay applied to each probe element. This method is valid for homogeneous and heterogeneous structures, isotropic and anisotropic materials, canonical geometries and complex shapes.

5. Future vision and summary

The designed structure of the pin-art ultrasound transducer not only offers flexibility of the device but also lowers the expense for repairment. In case some elements are damaged, the damaged elements can be easily replaced by good elements. In addition, every element can be removed from the main control board and be transplanted into a new board. This structural connivence offers the possibilities of assembling a specific arranged transducer (Fig 5) for different tasks by just changing the main control board. The simple and multi-task functional designed structure offers the possibility of easy operation for nonprofessionals. The main control board can be coupled together to form a larger transducer which can be used for some specific tasks.

In summary, we presented a newly designed pin-art ultrasonic transducer and its proposed capabilities in terms of half-flexible array design. The principle is based on the use of half-flexible transducer array to complex surfaces and the 3D model of surfaces are collected by vertical displacement of sub-element transducers. Using algorithm of arbitrary delay laws, the transducer can offer a high-quality ultrasonic. In addition, it is very possible to import varied sub-element transducer arrangement for muti-functionality. These potentialities make it a powerful tool for complex surface detection.

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