MEMS-Based Electrostatic Actuated Scanner Dedicated for Ultrasound Sensors

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Abstract

This paper concerns the design and fabrication of new transducer movers dedicated to 3D ultrasound sensors. Our MEMS-based movers were designed using CoventorWare finite element software to maximize the sector and rotation scan angles. These movers are fabricated on silicon wafers using the standard PolyMUMPs process. The design includes both a scanner actuated using four trapezium electrodes and a scanner actuated using vertical comb fingers. According to the simulation results, the required voltage to actuate this latter is significantly less than that required to actuate the platform using electrodes.

1. Introduction

Echography is a medical imaging technique which is used to explore surfaces and/or deep human organs. It uses an ultrasound beam with a frequency range from 2.5 to 10 MHz, which is reflected by tissues and organs. In order to have three dimensional ultrasound imaging, a transducer array is translated, rocked, or rotated to collect a series of two dimensional images that are later stacked to represent the three dimensions anatomy. The most common techniques used to collect this series are the free hand acquisition which includes the three basic components of acoustic, articulated arm, and electromagnetic positioners and the mechanical localizer in which the transducer array is rotated to perform a fan or rotational scanning using a step motor [1]. The first technique suffers from noise and scanning gaps which may reduce the image quality, particularly when high resolution imaging of small structures is required. The main disadvantage of the second technique is the vibrating movement of the motor when it goes from one step to another. This vibration turns out in artifacts which affect the image quality. In order to avoid these limitations, we propose to rotate a linear transducer array by using silicon scanner constructed by Microelectromechanical systems (MEMS) process. This device collects 2D images while moving at predefined spatial intervals. This leads to an imaging sequence that samples the volume of interest properly, without missing any region. In order to implement the proposed scanner, each transducer is mounted on a platform, which in turn, will be actuated to rotate for sweeping over the region being examined.

2. Design Characteristics

The design of the proposed ultrasound scanner consists of a rectangular platform attached to a frame. Both the platform and the frame are free to rotate with respect to orthogonal axes. This device is actuated using four trapezium electrodes; two electrodes are placed under the platform and two under the frame. The analytical model and the simulations of this microsystem have been done in [2]. The maximum platform scan angle is limited to around ±5° and the frame one is limited to around ±2°. Platform and frame pull-in detection simulations have been performed and they turned out to be respectively 290 V and 92 V. In order to increase the platform rotation angle and decrease the driving voltage, we propose to actuate the platform using vertical comb fingers. The relation between the rotation angle (θ) and the applied voltage (V) is

$$\theta = \frac{T}{K} = \frac{V^2}{2K}\frac{\partial C}{\partial \theta} \qquad (1)$$

where,

$$\frac{\partial C}{\partial \theta} = \frac{N\varepsilon_0[\frac{(t_c - g_0)^2}{\sin^2\theta_0} - d^2]}{g\theta_0}$$

t_c is the movable finger thickness, N is the number of fingers, K is the torsional spring constant, g_o is initial space between the fixed and movable fingers, d is the distance between the Torsional beam and the fixed finger, and θ_o is the maximum rotation angle (see Fig.2). This latter is limited by the polarity change of the electrostatic force as the top of the moving finger passes below the top of the fixed finger.

The predicted vertical displacements of the platform at different voltages are shown in Fig. 3.The required voltage to rotate the platform is less than that required

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to actuate the platform using electrodes. The scanner is supplied by passing a triangle wave through a high power operational amplifier to produce high voltage positive wave. The transducers are pulsed 128 times for each actuation in order to generate a 128 line image before sweeping the transducers to acquire another plane or two dimensional image.

3. Fabrication Process

The two scanning devices were fabricated using the MUMPs process [3], which has the general features of a standard surface micromachining process: polysilicon layers are used as structural material and can be suspended above the wafer surface. Phosphosilicate glass (PSG) is used as oxide sacrificial layers, and silicon nitride is used as electrical isolation between the polysilicon and the substrate. For the scanner actuated by electrodes, the gap between the platform/ frame and the electrode is limited to 2.75 microns due to MUMPs process maximum gap height limitation, This height is not sufficient to obtain large deflection angle. In order to raise the platform much higher over the electrodes, a flip-chip assembly technique is being used [4]. For the scanner actuated by vertical comb fingers, the second oxide has been etched by immersing the chip in bath of 49% HF.

4. Conclusion

MEMS electrostatically actuated platform is a promising technology for 3D ultrasound echography. We have modeled our microsystems analytically and numerically using finite element software. The proposed scanners offers a continuous scanning without leaving significant gaps, an important advantage in comparison with the 3D mechanical probe assemblies. The future work is to elaborate a fabrication process to have thick comb fingers in order to increase the rotation angle of the platform.

Acknowledgments

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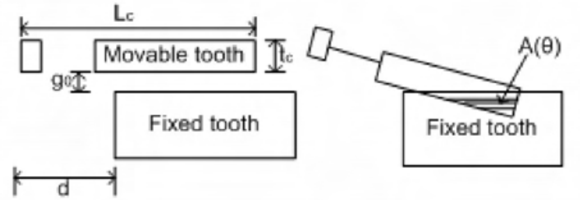

(a) (b)

Figure 1. Schematic view of the vertical comb: (a) in the initial state, (b) after voltage application.

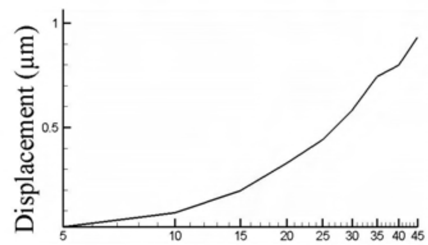

Figure 2. Numerical calculation of the scanner displacements as a function of the applied voltage

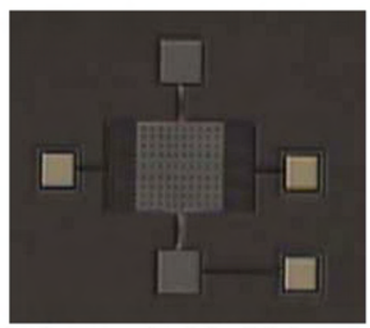

Figure 3. Photograph of the fabricated scanner

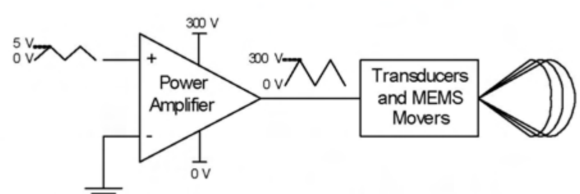

Figure 4. Block-diagram of driving circuitry