Design of Electrostatic Imaging System based on MEMS

M-X Li, X. Chen, X. Pan , J-S Kang

State Key Laboratory of Mechatronics Engineering and Control
Beijing Institute of Technology,5 South Zhongguancun Street, Beijing, PR China
chenxi@bit.edu.cn

ABSTRACT

The electrostatic imaging system acquires the contour profile of charged object by sensing the electrostatic field around the object. In this paper, an electrostatic imaging system is designed based on MEMS technology. The design scheme of electrostatic imaging system is proposed, where each imaging unit is designed on the principle of directional electrostatic theory. Then, a new structure of vertical vibration type was designed which increase 60% sensing area compared to our previous work. Based on this, the imaging array is laid by using the imaging unit, and the result of the imaging array is simulated. The simulation result shows that the imaging array can effectively achieve the function of imaging the object. It is also proved that the design of electrostatic imaging system is feasible and can improve the imaging resolution effectively.

Keywords: electrostatic detection, electrostatic imaging, MEMS system

1 INTRODUCTION

The amount of information captured from an object determines the understanding of an object. In the various characteristic information of the object, image information contains more information content. So imaging detection technology has got more attention from researchers. Compared with other imaging detection [1~4], electrostatic imaging, which uses electrostatic characteristics of object, has the advantages of good concealment, anti-interference and anti-stealth and it is valuable to research.

Only a small part of research institutions is engaged in the research of electrostatic imaging technology. Researchers at the University of Sussex have studied non-contact electrostatic imaging research applied to the human body surface [5]. In China, Beijing Institute of Technology studies non-contact electrostatic imaging of ordinary charged object and successfully develops a passive electrostatic imaging principle prototype, which is able to get charged object's contour by verification [6~7].

It is necessary to miniaturize the imaging system to improve the electrostatic imaging resolution. MEMS technology provides a feasible way for miniaturization of electrostatic imaging system with its characteristics of miniaturization, integration. The imaging unit, which is the electrostatic imaging MEMS sensor designed in this paper, is a kind of miniature electric field sensor with directionality and ability to detect electric-field of the object in specific directions. The electric field sensor designed in current studies could be classified into two types, which is solid [8] and vibration [9]. Both of them could detect electric-field all around, but vibration type has higher sensitivity, higher consistency and stability. In this paper, by adopting the design principle of vibration type miniature electric field sensor and combining the directional command of detection, we built a new structure of vertical vibration type induction electrode with larger sensing area. At last, the imaging array composed by the designed sensor is used to image the object.

2 INTEGRATED DESIGN OF MICRO ELECTROSTATIC IMAGING SYSTEM

The electrostatic imaging system is consisted of micro imaging unit, data acquisition and processing system. Electrostatic imaging array contains a plurality of electrostatic imaging sensing units. In the array, electrostatic imaging sensing units sense and detect electric-field around the object, and transform it into potential signals. The conditioning circuit is responsible for the signal pretreatment and the data acquisition card converting the signal from analog to digital. The image processing module generates potential signals captured by the imaging array, and further converting data to standard gray scale image. The overall design of the system is shown in Fig.1.

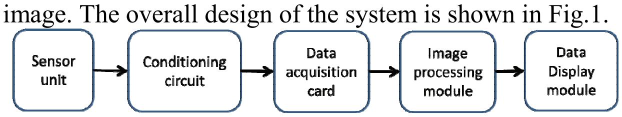
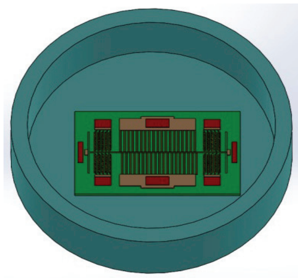


Fig.1 Overall design of electrostatic imaging system

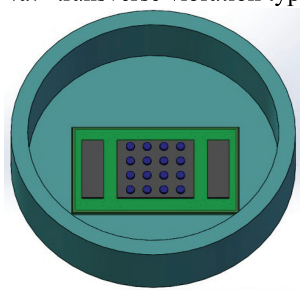
3 DESIGN OF ELECTROSTATIC IMAGING MEMS SENSOR

3.1 Design of sensing unit

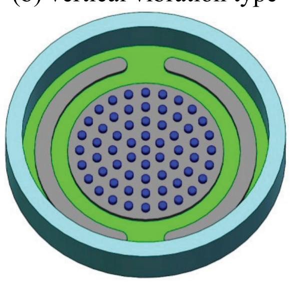
Based on the directional electric field sensor to get field information of a charged object in specific direction [10], we can image the charged object. The conditioning circuit, shielding cylinder and the electrode structure of relative vibration of shielding electrode and induction electrode constitute the electrostatic imaging MEMS sensing unit. In our previous work[11], we proposed two kinds of design schemes, which were vertical vibration type and transverse vibration type shown in Fig.2 (a) (b). In this paper, we design a new structure of vertical vibration type which increases 60% sensing area and improves the sensor sensitivity.



（a）transverse vibration type



(b) vertical vibration type



(c)new structure of vertical vibration type

Fig.2 Structure of electrostatic imaging MEMS sensing unit

The working principle of imaging MEMS sensing unit is shown in Fig.3. When it works, current signal *i* output by the induction electrode is input to conditioning circuit, and after operating by I/V conversion, differential amplifier, correlation detection and low pass filter, it transformed into the final potential signal.

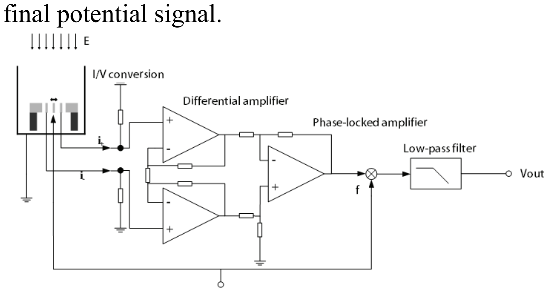


Fig. 3 Principle diagram of electrostatic imaging MEMS sensing unit

Choosing vertical vibration type sensing unit as an example, when the electric-field is vertical to the sensing electrodes of the sensor, the quantity of changed charge in the surface of a single sensing electrode in a vibration cycle is Δq, the total number of induction electrode is n, and the vibration frequency is f, then induced current of the sensor can be described as

$$i = \frac{dq}{dt} \approx n \cdot \Delta q \cdot f \tag{1}$$

After the current is processed by the I/V conversion circuit which has the equivalent resistance of Req, output voltage is obtained by

$$V = i \cdot \mathrm{R}_{eq} \tag{2}$$

Assuming the measured electric-field magnitude is E, dielectric constant is $\varepsilon 0$, and effective sensing area of sensor is A then according to the Gauss theorem, the total amount of induced charge of the sensor is

$$q' = \varepsilon EA \tag{3}$$

Therefore, induced current of the sensor can be expressed as

$$i = \frac{dq'}{dt} = \varepsilon_0 E \frac{dA}{dt} \tag{4}$$

Due to periodic vibration of the shielding electrode, dA/dt can be approximately regarded as a constant. So according to Eq.4, both of magnitude of the induced current and the output voltage of the sensor are proportional to the amplitude of measured electric-field.

3.2 Simulation analysis of the sensor parameter

Firstly, the directionality of electrostatic imaging sensing unit was simulated. The charged object is an infinite homogeneous positively plane, simulation result is shown in Fig.4(the arrow's point expresses the direction of electric-field, the color expresses the size of electric-field magnitude, red represents the maximum value and blue represents the minimum value), which proves that the existence of the shielding cylinder makes only the electric-field lines generated by object's partial parts in front of sensor can enter the sensor, which reflects directed detection in part. In the black box is the effective induction range, where electric field only has 30% direction distortion.

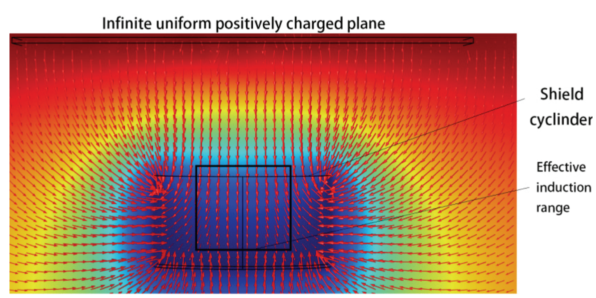


Fig.4 Effect of shielding cylinder to electric-field

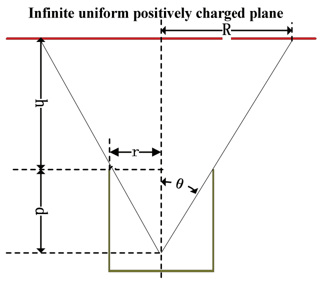


Fig.5 Simulation model of shielding cylinder

Directionality of electrostatic imaging sensing unit is determined by the shielding cylinder parameters, which includes shielding cylinder radius *r* and depth *d*. According to Fig.4, *r* should be large enough to avoid distortion of electric-field at the orifice of shielding cylinder. The size of electrode structure of the sensor is less than 2mm, and *r* is set to 7mm after analysis. To research the effect of *d* on the sensor's directionality, simulation model is established in Fig.5. *h* is the detection distance, and *R* is the ideal detectable circle radius when the shielding cylinder makes detection region decrease, then the formula is

$$R = (\mathrm{h} + d)\frac{r}{d} \tag{5}$$

Considered the effect of grounding shielding cylinder on the electric-field, the real detectable circle radius cannot be calculated accurately by Eq.5. In the simulation, the detected potential *V'* is calculated by MAXWELL, the detectable circle radius when the actual situation is simulated can be obtained as

$$R' = \sqrt{(\frac{2\varepsilon_0 V'}{\sigma} + \mathrm{h} + d)^2 - (\mathrm{h} + d)^2} \tag{6}$$

The quality measurement standard of the directionality of electrostatic imaging MEMS sensor can be expressed by η, which is calculated as follow

$$\eta = R' / R \tag{7}$$

When h=0.1m, $\sigma = 10^{-7}$C/m^2, simulation results are shown in Fig.6. According to the simulation results, when *d* is 5 to 7mm, η is the largest, the directionality of sensor is the best, but *R'* has reduced to almost *r*, and decreases rapidly with the increase of *d*. Therefore, considering the directionality, we select d=5mm as the shield cylinder's parameter.

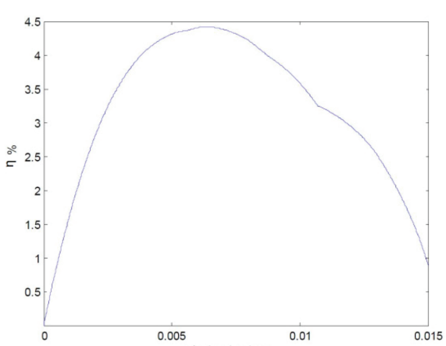


Fig.6 Relationship between cylinder depth *d* and η

4. SIMULATION OF ELECTROSTATIC IMAGING SYSTEM

4.1 Layout of imaging array

A single MEMS detection sensing unit can only obtain partial information of the charged object. To achieve electrostatic imaging of the object, it requires a plurality of sensors combined in an array. At present, imaging array's layouts includes linear, planar and honeycomb. Compared with other layouts, planar array has the advantage of simpler structure. In adjacent ways of planar array, compared to triangles or hexagon, the advantages of square adjacent is that each sensor can be corresponding to a pixel point of image, and the imaging effect is intuitive and specific [12]. So we choose the square adjacent of plane layout to the imaging array. Detection model is shown in Fig.9. The red block is the charged object. Sensors units are arranged in a matrix, and the interval is 20mm. In Fig.7, *i* and *j* represent the row and the column where micro-detection sensor is located in detection array.

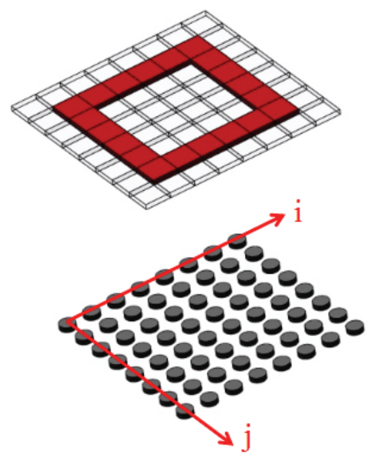


Fig.7 Scheme for the detection

4.2 Electrostatic imaging results

The electrostatic imaging array model was simulated by MAXWELL. When we set the size of electrostatic imaging array 1120mm×1120mm as the standard size, the electrostatic imaging system in this paper has 56×56 pixels, and the simulation results are shown in Fig.8. Compared to our previous work, which in reference [11]. We design a new structure of MEMS sensing unit, which increases 60% sensing area and improves the sensor sensitivity. Sensitivity enhancement makes the sensing unit detecting more accurate information about the charged object and increases the resolution of the image simultaneity.

It is obvious that the design of electrostatic imaging system based on MEMS has greatly enhanced imaging resolution and has a better imaging effect.

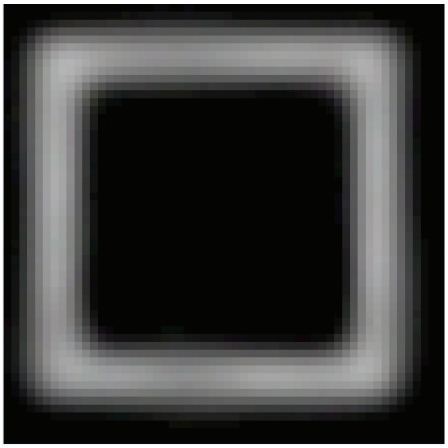


Fig.10 Grayscale image of charged object

5. CONCLUSION

This paper has designed an electrostatic imaging system by using MEMS technology. The electrostatic imaging system design can be effective in imaging detection by simulation. Compared with the design in reference [11], the designed system in this paper has advantages higher resolution. By further increasing sensitivity of the sensor, the image will be closely matched with the object's charged contour on the whole and the system will have a good applied prospect.

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