Vibrotactile using micromachined electromagnetic actuators array

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Vibrotactile using micromachined electromagnetic actuators array

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Abstract. One motivating application of this technology is the development of a tactile display interface, where discrete mechanical actuators apply vibratory excitation at discrete locations on the skin. Specifically, this paper describes the development fabrication and characterization of a 4 x 4 micro-actuator array of vibrating pixels for fingertip tactile communication. The vibrating pixels are generated by using an electromagnetic microresonator. The fabrication sequence and the actuation performance of the array are also presented.

1. Introduction

The need for tactile displays is motivated by their potential applications in a wide range of fields such as the entertainment industry (e.g. computer paddles), the medical world (e.g. virtual surgery training, remote surgery), sensory substitution systems (e.g. displays for the blinds), e-commerce (e.g. remote sensing of a material via the internet), the research world (e.g. study of mechanoreceptors), and many more. This explains why many research groups have a great interest on the design of practical tactile display [1]. There are five main approaches to tactile display technology. These are visual, pneumatic, electro-tactile, neuromuscular stimulations and vibro-tactile. In a visual display, the status of touch of the slave fingers is indicated by the appearance of an icon or via displaying the slave fingertip forces, digitally or graphically to the user. A pneumatics approach uses air jets, air pockets or inflatable bladders to provide touch feedback cues to the operator. The electro-tactile stimulation method provides electric pulses, of appropriate width and frequency. The neuromuscular stimulation approach provides the signals directly to the primary cortex of the operator's brain. Finally, the vibro-tactile approaches use vibrating pins, voice coils, or piezoelectric crystals to provide tickling sensation to the human operator's skin to signal the touch. The choice of the technology must be guided by such factors as the requirement in term of force and frequency, the cost, complexity, weight, comfort, noise, power requirement, invasiveness and the extent of liability of the device.

The majority of MEMS actuators have been piezoelectric or electrostatically driven due to their ease of fabrication and integration with other micro components [1, 2]. On the other hand, the fabrication of magnetically actuated components has generally been avoided due to lack of processing knowledge and the difficulty of integrating magnetic components with other Microsystems and circuits. In spite of poor scaling of magnetic forces, there is at present a growing interest in magnetic
micro-devices, due to the ability of magnetic-based actuators to generate large magnetic forces. Several attractive features of micro-magnetic devices that make them strong candidates for use in MEMS applications are the use of small size of micro-coils that can generates large magnetic field gradients and correspondingly large forces [3, 4].

Magnetic micro-actuators have been fabricated for many years and, until now; they were realized simply as scaled-down versions of their macroscopic counterparts, such as electromagnetic motors, magnetometers and sensors. Their electromagnetic interaction is mainly due to the use of external micro-coils or micro-permanent magnets [4,5]. It is well known, however, that it is a challenging, time consuming and expensive task to construct micro-coils using classical methods, or to hand-machine large pieces of permanent magnetic material into micro-permanent magnets, for the purposes of constructing micro-devices. In this study, we propose a prototype of vibrotactile display design with fabrication accomplished in a continuous batch process, without addition of steps such as manual assembly.

This paper presents our work in optimizing the design of tactile display based on electromagnetic actuator. First we have used a conventional solution compatible with the mm size. Static and dynamic testing of the actuators has been performed. The experimental data are compared with theoretical results and a good agreement is obtained. In perspective of this work a design of a completely integrated device with performance equal like higher to the assembled is proposed.

2. Design of the actuators array
The device to be fabricated is composed of an array of 4X4 cantilever beams, actuated at their first flexion mode resonance. Each beam is driven independently by 16 microcoils producing the magnetic field gradient necessary to drive the magnet bonded at theirs free end (Fig.1). The cantilever dimensions are chosen in order to obtain a first flexion mode resonance frequency of 250 Hz corresponding to the maximum sensitivity of the fingertip fast cell (RAII).

![Fig1. General layout of the 4X4 array of independent magnetostatic actuator](image)

Analysis of the conventional actuator
As a prototype, we built in conventional manner a 4X4 array of actuators. A photograph of a fabricated device is shown in Figure 2. The actuator consists of a cantilever beam made of polysilicon with integrated permanent magnet (Fig.3) and the coil is placed beneath the beam free end. The direction of the magnetic field produced by the coil is the same as the permanent magnet alignment, an attraction force is produced and vice versa.
The magnetic field generated by the coil was simulated using Vector field software, as shown in Figure 3. The fabricated coil consists of 15 turns of copper wire with diameter of 100µm. The inner and outer diameters were 800µm and 1400µm, respectively. In the coil center a ferrite core is added in order to improve the magnetic field intensity and also to minimize the permanent magnets interactions. With the Biot-Savart law the magnetic force was simulated at 1 mN at a driving current of 200mA. Experimentally we have obtained in static analysis and in the same conditions the beam deflection of 12µm. using small deflection theory this value will correspond to 1.2mN which is in good agreement with theoretical result.
The dynamic behavior of the magnetic actuators has also investigated. The resonance frequency and amplitudes vibrations of the cantilevers were measured. For alternative driving current of 30mA, vibration amplitude of 450µm was obtained at the first mode flexion resonance frequency of 152Hz. These frequency resonances take into account the magnet mass effect. The second mode of flexion is also observed at 450Hz with vibration amplitude of 200µm.

**Sequence fabrication of the electromagnetic actuator array with high level of integration**

Cantilever beams are processed by Reactive Ionic Etching (RIE) on silicon wafers, and then released after KOH wet etching (Fig. 4). Permanent NdFeB magnets are obtained by using miniature magnet or by mixing particles to a PDMS mother solution at approximately 1/1 mass ratio[6]. The resulting polymer is then diced and bonded to the cantilever tips. This new PDMS-based processing method provides convenient shaping and handling of the magnetic materials. To obtain the same performance in term of magnetic field intensity, the micro coils to be used should present a thickness of several of tens micrometers. This can be obtained by using silicon as the moulding material; electroplating moulds were patterned into silicon by deep reactive ion etching (DRIE)(Fig.5) [7]. The optimization of the fabrication process and the device characterizations are in progress.

*Fig. 3: Simulated vector field Hz for a magnet (1mm3) and 0.5mm spacing between magnet and coil, the driving current is 200mA (left without core, right with core)*
Fig. 4: Fabrication process of the vibrotactile display device. Deep RIE etching is used for the cantilever processing, and coils are Cu electrodeposited.

Fig. 5: Micro coils fabrication: (a) surface profile of silicon trenches formed by deep RIE etching 6µm/14µm; (c) CONFOCAL Microscope visualization of the fabricated microcoils

3. Conclusions and future works
From the preliminary tactile experimental results, it appears clearly that this tactile device is able to present vibrotactile stimulation to the human finger tip. The performance of this array of actuators in terms of frequency and displacements responds to the requirements of the practical vibrotactile device. In future work the complete integrated permanent magnet actuator will be fabricated and characterized. Future work will include also a tactile stimulation evaluation.
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References


