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Haptic Technologies for MEMS Design

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Abstract. This paper presents for the first time a design methodology for MEMS/NEMS based on haptic sensing technologies. The software tool created as a result of this methodology will enable designers to model and interact in real time with their virtual prototype. One of the main advantages of haptic sensing is the ability to bring unusual microscopic forces back to the designer's world. Other significant benefits for developing such a methodology include gain productivity and the capability to include manufacturing costs within the design cycle.

1. Introduction

The Micro-Electro-Mechanical System (MEMS) market is growing very fast and is currently estimated at $11 billion and forecasted in 2007 over $26.4 billion according to a recent In-Stat market survey. Presently, high-volume commercial MEMS are restricted to devices such as accelerometers, inkjet print heads, and digital micro-mirrors for large scale displays. Furthermore, MEMS technology is still based on design tools borrowed from the semiconductor industry. The design stage requires also substantial amount of manufacturing and fabrication knowledge as MEMS tend to be highly integrated [1]. Our goal is to create a digital tool using haptic technologies for the design and manufacturing of MEMS. Haptic devices are known to be up to 90% more productive than 3D CAD used in physical modelling [2]. To the best of our knowledge, we are the first research team to investigate haptic sensing technologies for MEMS applications. Another motivation for this work is the ability for this tool to be used to train and educate scientists and engineers. At micro-scale, forces like surface tension, friction, electrostatic forces tend to dominate over mesoscopic scale forces such as gravity or magnetic forces. In addition, there are many phenomena which are imperceptible to us such as the Casimir effect [3] or stiction, which can affect the operation of MEMS at the micron scale. By using haptic sensing, this type of failure can be detected and corrected at the design stage.

2. Motivation

Currently, there is a lack of modeling and simulation methodology for precise performance verification of the MEMS devices. In addition, tools available are not efficient to detect potential fault and defects within the manufacturing process, and moreover simulation tools existing for MEMS technology cannot predict the effect of complex external or internal environments parameters [1]. Furthermore, MEMS technology is still based on older design tools and is fabricated on a "trial and

error" approach, MEMS are highly integrated and it is difficult to separate device design from the complexity of fabrication leading to a high level of manufacturing and fabrication knowledge [2].
Haptic technology will enable designers the possibility to scale-up micro-assemblies which can consists of million of parts to a human ergonomic scale and, then scale the product back to its original size. These properties enable the reduction of manufacturing and maintenance times. Based on the benefits that haptic technologies can provide in MEMS modelling and simulation as described in table 1, we believe that haptic sensing technologies will have a considerable impact on the MEMS market in terms of productivity, cost and efficiency.

Table 1: Needs of haptic technologies for MEMS

Application	Needs	Benefits of haptic technologies
CAD/CAM design	-Guide designers during assembly and disassembly process -Conception -Tolerance	-Manufacturing of mould at micro-scales for LIGA processes - Sense surface, shape of components, deformation - Sense and effect of forces at nano, micro-, meso-scale structures
Virtual Prototyping	-Replace physical prototype by virtual models -Enhance product development	-Combination of physical and digital modeling -Improve manufacturing lead times
Visualization	-Analyses of any parts of the system request -Ergonomic Analysis -Cost of manufacturing	-Scale-up/down -Increase information flow between user and the computer -Better understanding
Maintenance	-Diagnosis -Verification	-Quick analysis of any default, the cause and solution -Security
Training	- Simulation - Useful for application related manipulation	-Force-feedback -Sense gravity, inertia -Motion of components

3. Haptic sensing technologies

The term haptic originates from the Greek "haptesthai" and means the sense of touch with both tactile (cutaneous) and kinesthetic (proprioception) feedback. The purpose of haptic technologies is to immerse the user in a Virtual Reality Environment (VRE) by displaying and rendering forces in response to the user interaction via the sense of touch, known as haptic rendering. This project is based on the Fish-Tank system that immerses the user in the synthesized environments (figure 1.a). This is achieved by a projection of the graphic scene on a mirror via a monitor and a Head Mounted Display (HMD) hold by the user (figure 1.c). The haptic interface used in this project is the PHANTOM Desktop from SensAble technologies; this is an analog interface enabling the interaction of the users with the Virtual Environments with haptic rendering through touch [4]. This haptic device is a "pen" located at the end of an arm controlled by electrical motors and enabling the user a 6 Degree Of Freedom (DOFs) to render synthesized forces and torques during object interactions (figure 1.b). This new type of interfaces differs from current computer systems and they are changing the way that we are perceiving/manipulating digital information. Haptic research is a recent progress in digital tool that combines physical and digital modelling. Until recently, there were no Computer-Aided Design (CAD), Computer-Aided-Industrial Design (CAID) or Computer-Aided Manufacturing (CAM) tools available for industrial designers to interact with the design through touch.

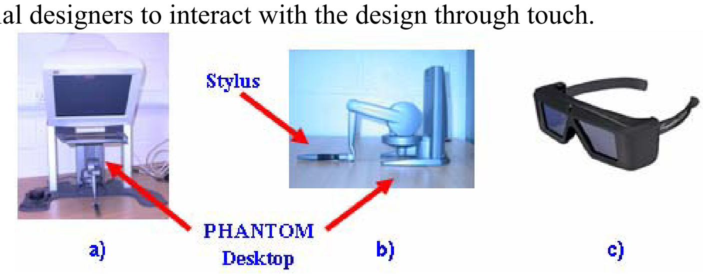

Figure 1: a) Haptic interface b) PHANTOM Desktop d) Head Mounted Devices

A haptic system consists of two loops, called haptic loop and display loop that need to be maintained with an update rate of 1 KHz and 30 Hz, respectively (figure 2.a). The display loop must be updated at 30 Hz since the Human Visual System (HVS) has a flicker fusion frequency around 30-60 Hz and humans are not able to discriminate images with a higher update frequency. The update rate of the haptic loop has been set at 1 KHz to avoid force artefacts and due to the human being able to detect discrete events at less 1 KHz. This haptic interface enables the user to feel the realism of objects such as its physical rigidity, resistance, texture. Components/surface properties such as friction, stiffness, and roughness of object are also rendered in a way similar to that of the physical object. By using haptic technology, humans will be able to perceive and understand many phenomena that happen in the real world, and are imperceptible to us such as the Casimir effect [3]. In general, this effect cause surfaces of components to attract to each other, therefore it represents a potential deleterious effect on the performance of MEMS. In the worst case scenario, failure of the systems subjected to this force can occur. An example is the permanent stiction of surfaces. In such circumstances, humans lack the senses to perceive this phenomenon. By using haptic technology, humans will be able to perceive and understand these phenomena. Moreover, haptic sensing will guide the user in his design process, so user mistakes will be detected at the early development stage of a prototype and additional costs will be avoided. These benefits of haptic technologies are unachievable with one-way Human Computer Interaction (HCI) (figure 2.b).

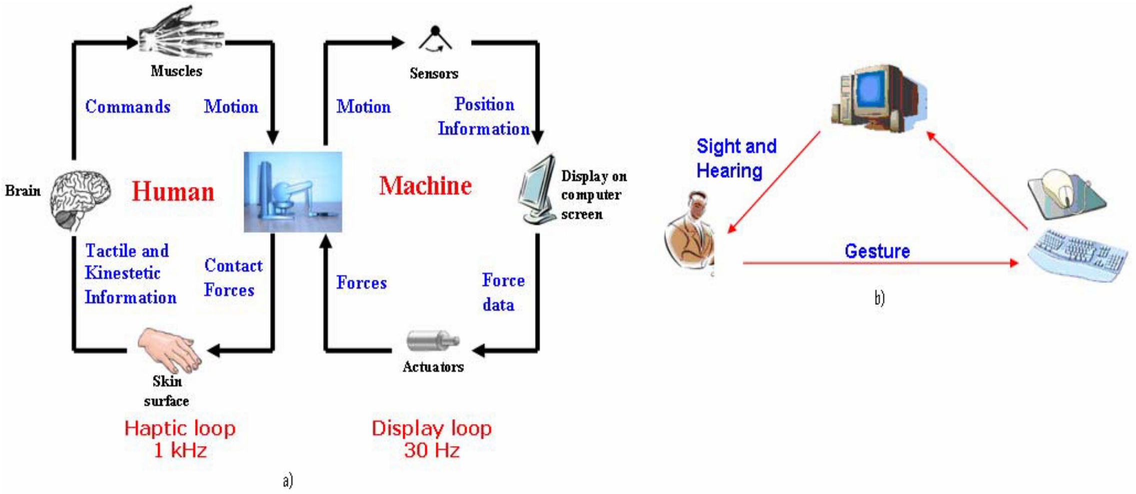

Figure 2: a) Functional diagram of a haptic system b) Current Human-Computer-Intearction

In addition, in VEs, scaling down MEMS allow designers to gain more information and better understanding of their devices/components since the designers will be immersed in the VR and any part of the system will be accessible. The different needs of MEMS modelling and simulation methodology for precise performance verification of MEMS products are summarized in table 1.

4. Conclusion

By considering (i) the different needs of haptic technologies for MEMS, (ii) the lack of modelling simulation methodology for precise performance verification of the MEMS devices, (iii) the highly intensive market for faster computing capability in smaller computers which leads to a greater miniaturization, we believe that haptic sensing technologies will enable designers to reduce manufacturing time and cost and increase their understanding of microscopic forces.

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