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Virtual broker system to manage research and development for micro electro mechanical systems

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ABSTRACT

This works presents an analysis of the need for efficient managerial tools in order to address various challenges and opportunities for the micro and nano-electro-mechanical-systems (MEMS/NEMS) industry, and to expedite the development cycle and shorten the total time from idea to market for devices based on these technologies. A methodology to provide support to the MEMS/NEMS community (i.e., researchers, designers, and entrepreneurs) is proposed and described. This methodology offers guidance during the early stages of MEMS/NEMS product development, provides means to manage research and development, and acts as a virtual broker in order to coordinate collaboration among various organizations to optimize the use of existing fabrication infrastructure. Innovative products based on MEMS/NEMS have made rapid improvements in terms of functionality, cost, performance, etc. However, many applications and devices based on these systems are still in the research phase, struggling to reach to a commercial stage.

1. Introduction

Micro and nanotechnologies (MNTs) tend to be disruptive technologies that can provide new solutions for ancient problems. A subcategory of MNT is the *micro-electro-mechanical-systems* (MEMS), sometimes also referred to as *microsystems* or *micro-machined devices*. MEMS are defined as devices with dimensions on the order of micrometers that convert between electrical and some other form of energy. MEMS rely principally on their three-dimensional mechanical structure for their operation (Banks, 2006). This same definition is extended to *nano-electro-mechanical-systems* (NEMS) when the physical features (e.g., dimensions of gaps or line width, step height) of a device are smaller than 100 nm (Lyshevski, 2001). A number of commercial applications of systems based on MEMS/NEMS technologies are already being mass produced. However, many major potential applications are still under development (Tolfree & Jackson, 2008). Despite the fact that more widespread dissemination of MEMS/NEMS devices could significantly improve quality of life, the emergence of commercial products based on these technologies has been relatively slow (Grace, 2007; Walsh, Elders, & Giasolli, 2002). These systems evolved from a very well known industry: the semiconductor industry. However, there are substantial differences between the semiconductor industry and the MEMS industry. Eijkel et al. (2006) mention that the lack of a true unit cell for MNT limits the learning curve experienced in the semiconductor industry. At the same time, there are plenty of management, planning, and manufacturing tools that have been successfully used in the semiconductor industry but they are often not effective when dealing with disruptive technologies like MEMS. Some devices based on these technologies can take more than 20 years to reach a mass production stage (Bryzek et al., 2006). Some authors attribute high idea-to-market times to the complexity of the manufacturing process (Breit & van Kuijk, 2010; Gardner, Varadan, &

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Awadelkarim, 2001; Maseeh, 2000; Schmidt, Wagener, Popp, Hahn, & Bruck, 2005). In order to improve this idea-to-market time, it is important to clearly understand the current status of the MEMS industry, identify the areas of opportunity, and make optimal use of resources (i.e., computer technology, processes, knowledge, human capital, etc.).

The main objectives of this work are to (1) provide a formal analysis of the various obstacles that the MEMS designers are facing while trying to take their designs from an idea to a commercial stage, (2) shed some light on the multiple opportunities to develop management tools (e.g., product development management, knowledge management, R&D management) for the MEMS/NEMS industry, and (3) offer an initial solution to mitigate some of the identified challenges. In order to provide a relevant scientific contribution, we designed a methodology, to ultimately be expressed as a software tool, which will be implemented as a knowledge-based system to help researchers, development groups, and lead users in academia as well as in industry. By utilizing this system, we aim to improve the time to market for MEMS/NEMS development by leveraging ideas presented elsewhere (Erzurumlu & Erzurumlu, 2013; Schreier & Prügl, 2008; Shin, Shin, & Rao, 2012), where users can produce important innovations within the technological domains of manufacturers' expertise and manufactures can perceive innovations as more commercially attractive.

1.1. Paper layout

Section 2 presents a detailed description of the research methodology that was used during this work. In Section 3 we provide an analysis of the main obstacles and challenges for the MEMS industry. Two main categories were defined to group these challenges: technological challenges (Section 3.1), and managerial challenges (Section 3.2). Various opportunities for the MEMS industry are presented in Section 4, and a system for research, knowledge and technology (RK&T) management that provides means to alleviate the challenges and try to capitalize on the opportunities in the MEMS industry is described in Section 5. Section 6 presents the conclusions and final remarks of this work.

2. Methodology

In the first part of this work we use a descriptive research approach to investigate the current state of affairs of the MEMS industry, with an intention to identify, synthesize, and tie together different perspectives regarding obstacles for MEMS/NEMS development and commercialization. By doing this, we are able to understand and summarize the main challenges and areas of opportunity of this industry. In the second part of this work, we use a prescriptive research approach to propose an algorithmic (and ultimately computerized) methodology as a contribution to tackle some of the main problems in the MEMS/NEMS industry.

We are proposing a *virtual broker* methodology that improves various aspects of the commercialization process for MEMS/NEMS products by managing knowledge generation and efficient utilization of existing fabrication infrastructure. In order to properly design this methodology, we perform an extensive literature review of the evolution and progression of MEMS technology to understand the current state of the MEMS industry. We examine the industry as a whole, we review specific references on how MEMS/NEMS technology has been managed, and we analyze the main hurdles and opportunities in the commercialization path for products based on these technologies using several perspectives. During this analysis, we were able to identify critical features required for a new MEMS product to become a successful commercial product. We examined the *Digital Light Processor* (DLP) technology developed by Texas Instrument Incorporated (2009) as a case study in this analysis. Finally, we present a system that uses a *virtual broker* methodology to manage knowledge and optimize the use of existing fabrication infrastructure to improve the MEMS/NEMS development cycle.

3. Challenges for the MEMS industry

Despite all the benefits and potential that MEMS/NEMS technologies have, there are some challenges that need to be addressed. Four challenge types have been identified: *technological*, *commercialization*, *information* and *management tools* challenges. In order for an idea to break through these challenges and reach the commercial stage (i.e., find a market), it is necessary for it to:

- provide a unique functionality,
- be reproducible and reliable, and
- provide economic benefits.

As shown in Fig. 1, if an idea lacks of any of those components the potential of getting to a commercial stage is low, even if the idea is based on a strong technology.

According to Petersen (1982), the most critical challenges (from a technology perspective) for the first fully actuating/sensing MEMS device, were: reproducibility and predictability of resonance frequencies, temperature stability, and potential limitations on lifetime due to fatigue. The first challenge is a manufacturing challenge. The fabrication processes used to build the device were not well characterized; hence controlling the process was problematic, impacting the reproducibility of the device. The second and third challenges had to do with problems on material selection and design considerations. Similar challenges are still present in many MEMS designs today.