CAD Challenges in BioMEMS Design

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ABSTRACT

The ability of micromachining, or MEMS, technology to directly manipulate micron- and nanometer-sized objects makes it an idea technology for a wide range of biological and biomedical applications, and has led to a subfield in bioMEMs design. Although BioMEMS is attracting substantial attention and research, development has been hampered by the lack of computer-aided design tools. The available tools are far behind those for integrated circuit design, and therefore successful bioMEMS designers require very sophisticated processing expertise. It is the purpose of this paper to encourage research in this rapidly evolving computer-aided design field, by providing the briefest of summaries and an extensive set of pointers to literature.

1. INTRODUCTION

Micromachining, the core technology for MEMS, is the ability to fabricate micro- and nanometer-sized mechanical parts, and was initially a by-product of the enormous research investment in semiconductor fabrication. Now, though, micromachining is a thriving research enterprise that exploits techniques which are very different from those used in processing semiconductor wafers. The ability of micromachined to generate devices which directly manipulate micron- and nanometer-sized objects makes it an idea technology for a wide range of biological and biomedical applications.

The use of micromachining for biological applications can be divided into two categories: analysis and diagnosis (in-vitro), and internal use (in-vivo) [4, 5]. These two applications of micromachining generate very different challenges. Most of the in-vitro applications of micromachining are ones in which the goal is to improve existing analyses by accelerating processing, improving accuracy, or reducing cost. Such micromachined devices must be carefully optimized, as the devices will only be successful if they provide substantial improvement over existing techniques. Currently research on in-vitro applications of micromachining are labs-on-a-chip [1, 2, 3], DNA sequencing [7, 8, 9, 10, 11], cell seperating and isolation [12, 13], and blood testing [14, 15].

Unlike in-vitro applications, which often have to compete with existing approaches, many of the current in-vivo applications of micromachining are ones in which there is little or no treatment alternative. Such applications of micromachining are inspiring, and include approaches for continuous glocose monitoring [16], neural-stimulation [17], retinal implants [18], and artificial livers and other tissues [19, 20]. In-vivo micromachined devices are unlikely to appear in the near term, there are many difficult challenges such as the problems of energy havesting [6] and developing biocompatible processing [21, 22, 23, 24].

The typical approach to designing most bioMEMS devices involves using a simplified analytical model of a design, followed by the creation of many different design prototypes, some of which might function to specification. While this approach leverages the ability of micromachining technology to make many types of devices at once, such a prototyping approach is not likely to succeed in any but a research environment. As any integrated circuit designer knows, optimization using prototypes is too expensive and time-consuming, and does not identify failure mechanisms leading to unreliable designs. The end result is an unreasonably long time-to-market, and a reliance on extremely conservative design practices. In the sections below, we describe the present state and future needs for design tools for bioMEMS, and hope to encourage researchers to develop the tools desperately needed in this emerging field.

2. A BRIEF HISTORY OF CAD FOR MICROMACHINING

Computer-aided design systems for micro-electro- mechanical systems [54, 55, 56] (the genesis for the now nearly ubiquitous name of MEMS) began in the mid-eighties, with the primary focus being on three-dimensional model generation [32, 33], integral-equation based algorithms for fast electrostatic analysis of complicated three dimensional structures [34, 35, 36, 37, 38], and methods for solving coupled partial differential equations [39, 40, 60, 41]. During the mid-nineties, when surface micromachined polysilicon looked like it would become a widely used foundary process, the CAD for MEMS effort bifurcated. Specialized systems for micromachined polysilicon devices were developed, and these systems exploited the specifics of the micromachining process to create a very efficient hierarchy for simulation, extraction and optimization [28, 29, 30, 31]. The developers of more general CAD for MEMS systems [25, 26, 27] attempted to achieve the same goal by focussing on using model-order

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reduction to extract higher-level models from the coupled partial differential equation descriptions of MEMS, using either data-fitting [42, 43] or projection [44, 45, 46, 47, 48, 49, 50].

3. DIRECTIONS FOR BIOMEMS

The application of micromachining to biological applications requires complicated structures that process fluid, such as mixers, separators and pumps. This fluid handling requirement nearly eliminates the use of surface micromachined polysilicon, and even silicon has been pushed aside as the material of choice. The cost of processing silicon, at least for small numbers of devices, and its reactivity, has ushered in a move to other materials [21, 22, 23, 24]. From the perspective of CAD development, it is clear that tools for BioMEMS must handle fluids, and must handle very general three dimensional structures. For microfluidic devices intended for use in molecular seperation, the length scales are such that noncontinuum fluid effects must be considered [57, 58, 59], and therefore hybrid approaches which combine molecular and continuum models being developed [64, 65, 66, 67]. For devices used in processing cells, faster techniques are needed for analyzing cells in flow [60, 61, 62, 63]

In addition, the wide variety of structures being developed implies that generating the models for system-level simulation will depend on a combination of efficient fluid simulation and model extraction techniques. The required techniques may include approaches similar to the robust nonlinear model order reduction strategies being developed for nonlinear circuit model reduction [50, 51, 52, 53], but will also involve approaches where the interaction is a surface or region, rather than a few ports [68, 69, 70]. Finally, automated device optimization will likely require some form of parameterized model reduction[71, 72, 73].

4. CONCLUSIONS

In this paper we attempted to briefly survey the current challenges to providing CAD tools for designers of bioMEMS devices, and to provide an variety of pointers to the literature. Our main purpose was to encourage students interested in this area, and to aid them in getting started in this rapidly evolving computer-aided design field. This summary was supported by the National Science Foundation, and the Singapore-MIT alliance. Much of the research described above was supported under a variety of DARPA-sponsored programs.

5. REFERENCES

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