Abstract
This paper presents the use of a knowledge based system and a knowledge sharing environment to support the design of micromechanisms. Based on the experience of a design project, we discuss knowledge representation about the function and behavior for supporting functional decomposition. For the knowledge sharing environment, we have extended a finite element analysis system to allow the designer to perform analysis over the network. We also show the use of a multimedia news system for coordination of a design team.

1. Introduction

The micromechanism is a challenging field of engineering, in which mechanical, electrical, and material technologies are integrated together. There are several computer-aided design systems to support the designer to explore this new field, including ASEP [1] of University of Neuchatel, MEMCAD [2,3] of MIT, CAEMEMS [4,5] and MiSTIC [6] of University of Michigan. The central idea of these systems is the use of computer simulation. Their common goal is to perform calculation of geometrical and material properties from the information of fabrication processes, or to simulate electrical and mechanical behaviors. Since the behavior of a micromechanism can be complex and different from a mechanism of an ordinal size, their approach is obviously of great importance for the micromechanism design.

In this developing field, however, there are a lot of potential possibilities to create novel concepts. To investigate a new concept, it is crucial to search for alternative design principles and evaluate in various aspects. To make an approach to the support of this design process, we study the role of design knowledge. The approach may be called a knowledge centered approach, in contrast to the simulation centered approach. The knowledge centered approach includes providing knowledge bases for reasoning about the design object. In a broader sense, it also aims at supporting a team of designers to share knowledge in various formats, including documents, models, and computer programs that contain knowledge in the algorithms.

In this paper, we present two research directions of knowledge centered design support for micromechanisms. The first direction is the support of functional decomposition and physical embodiment. We show that knowledge about functional decomposition and physical realization can be implemented in a knowledge-based design system called SYSFUND. The second direction is
the support of collaboration over the network. A project team whose members work asynchronously is supported to form a project team by sharing information and design tools. We show a finite element generator and solver that can be used through an user interface on the World-wide Web. We also show the use of multimedia news system for information sharing.

2 Design of micro accelerometer

In order to study the design process of micromechanisms, we have been working on a project of a micro-scale acceleration sensor (below called a micro accelerometer). Micro accelerometer is one of the successful applications of the micromechanism technology. Possible applications of the micro accelerometer are passenger safety systems and controlling of dynamic vehicle suspension. There are commercialized products, as well as interesting concepts proposed by many groups.

Our project team of the micro accelerometer design is inter-disciplinary, including specialists of micro fabrication processes, mechanical design, material design, and finite element analysis. They are located at the University of Tokyo, University of Cambridge, and Matsushita Research Institute Tokyo.

In the beginning of design, we made a list of possible physical effects that translate an acceleration into any measurable quantity. The list includes the change of an electric resistance caused by deflection, the induction of a voltage by a motion of a coil, the change of a capacitance, the piezoelectric effect, and the tunnel current effect. The resistance, the piezoelectric, and the capacitance concepts had been tried by other groups, and the induction was not suitable for minitualization. So we decided to proceed with the tunnel current effect concept.

A cantilever with a small gap in the end was proposed for the realization of the micro accelerometer. A tunnel current that goes across the gap is observed to detect the change of the distance of the gap. The gap is created by the technique of focused ion beam cutting [9]. In this process, a concentrated ion beam is shone onto a suspended silicon bridge to make a cut at an angle of 45 degrees.

The cantilever is pulled down by an electrostatic force from the substrate to the position at which the gap comes to a specific distance. When the tip of the cantilever moves due to an acceleration, the amount of a tunnel current across the gap changes. The change is given to the voltage of capacitor, so that the gap is maintained at a constant distance. The amount of feed back is read out as an indicator of the acceleration.

The first version of layout had a uniform cantilever. It turned out to be too light to cause an enough deflection. Then the cantilever was redesigned to have a lumped mass supported by two arms in both sides. A picture of this layout is shown in Figure 2.

3. Representation of design knowledge

3.1 SYSFUND

For the implementation of design knowledge, we used SYSFUND (Systematization tool for functional design and synthesis) [10]. SYSFUND is a software for building functional and physical knowledge bases for the use of modeling and reasoning about the design object. SYSFUND uses a modeling framework called FBS
(Function, Behavior, and State). In the user interface of SYSFUND, an FBS model is presented as a graph of components of the function, behavior, and structure. The user can build an FBS model by combining these components that are stored in the system database.

The functional part of the FBS model represents how an abstract function is hierarchically decomposed to concrete sub-functions. A functional component consists of a verb and a target object that receives the effect of the function. In building a functional hierarchy, the user may ask SYSFUND to suggest possible decomposition of a functional component to sub-functions. If there are some known functional decomposition stored in the database, the user can choose one of them.

The behavioral and structural part of the FBS model represents how the functional structure is translated into physical embodiment. The user constructs the behavioral and structural part by combining so-called physical features. A physical feature is a causally linked collection of physical phenomena and structural elements. For a selected functional component, SYSFUND suggests possible embodiment to associated physical features.

3.2 Model of micro accelerometer

We put in SYSFUND functional components and physical features that are used for the design of accelerometers [11]. Each of the functional components is a transformation from an input quantity to an output quantity. Although it is restricting, we assume that this representation can cover a wide range of known functional components.

The functional equivalence was defined as being the same input and output quantities. Based on this definition, we made SYSFUND to look for all possible sequences of functional components that have the same input and output as an overall functional component. For a given overall function, if some sequences of components of sub-functions is found to be equivalent, they are used as candidates for functional decomposition.

Figure 3 shows an FBS model of the micro accelerometer. Functional components are presented in the upper area of the window, and physical features are in the lower area. Vertical links across them show the correspondence between the functional decomposition and the physical embodiment.

In simulating the design of a micro accelerometer, the overall function

\[ f_0: \text{to transform an acceleration to a change of voltage} \]

is decomposed into the following sub-functions.

\[ sf_1: \text{to transform an acceleration to a force} \]
\[ sf_2: \text{to transform a force to a deflection} \]
\[ sf_3: \text{to transform a deflection to a change of a distance} \]
\[ sf_4: \text{to transform a change of a distance to a change of electric current} \]
\[ sf_5: \text{to transform a change of electric current to a change of voltage} \]

Each sub-function is associated with physical features. In the function window, when the user selects one of the sub-functions, SYSFUND suggests associated physical features. In this case, physical features p1 to p5 are selected for implementation of sf1 to sf5.

\[ p_1: \text{motion of a mass caused by a force} \]
\[ p_1: \text{distortion of a cantilever connected to a mass} \]
\[ p_3: \text{motion of two objects with a gap between movable and fixed objects} \]
\[ p_4: \text{a tunnel current across a narrow gap} \]
\[ p_5: \text{conversion from an electric current to a voltage} \]

3.3 Scale analysis tool

As an extension of SYSFUND, we built a tool to study
the scale effect. This tool is intended to support the designer to identify the relative magnitude of influences in a small dimensions. Equations for the scale analysis are associated with related physical features. For instance, the equation that describes the amount of deflection of a beam is associated with a physical feature the bending of a beam.

The scale analysis tool is depicted in Figure 4. Parameters of the examined equation are presented in visual scales and numbers.

The user may change the value for a parameter by manipulating the scale or typing in a number. The value for the studied parameter is automatically calculated and shown on the display. The calculation is carried out by Mathematica running in the background. The equation in Figure 4 is the primary resonant frequency of a beam. It tells that if the length of a beam is reduced to 100 micrometers, its resonant frequency rises to the order of 100 kHz. This fact is an advantage for a micro accelerometer, since the dynamic range is wider than that of an accelerometer of a larger size.

4. Collaboration over the network

4.1 Support of finite element analysis

In the micro accelerometer design, knowing the dynamical behavior of the cantilever is important to determine dimensions. the deflection of the cantilever must be large enough to be able to detect an acceleration. At the same time, the tunnel current tip must be placed in a position in which the primary or secondary oscillation modes do not interfere the measurement.

To figure out the best layout by calculation, it is necessary to iterate finite element analyses. To do so, to build a finite element model in each iteration is a problem for the designer. Our solution to this problem is to use an automatized finite element analysis system. The system developed by Yoshimura et al. [12] generates a finite element model from a geometry model along with analysis conditions. We have extended the system so that the user can modify the dimensions and submit an analysis over the network. The system regenerates finite elements, perform a simulation, and return the result to the user. The analysis conditions, including boundary conditions and mesh density specification, are set once in the beginning by an expert of analysis and reused in later iteration. This interface is implemented in HTML using FORM and Common Gateway Interface (CGI). From any local machine that has an access permission, ti can be used just as for other WWW documents.

Figure 5 depicts the user interface of the remote analysis system. The designer define dimensions of the micro accelerometer. Then the system invokes a mesh generator on a remote server to crate finite elements. The mesh generation process takes about five minutes to complete. Then the finite element model is sent to a solver MARC that runs on the same or another server. Resonant frequencies of the micro accelerometer for the given dimensions are returned to the user.
4.2 HyperNews

In the case study of micro accelerometer design, we recognized that information sharing is an extremely important element to coordinate remote collaboration. Especially in our case, the design was so critical that every elements of the design project were dependent on others. For instance, it was important to for the finite element analysis to know ranges for dimensions feasible with respect to manufacturing technology.

To facilitate information sharing, we used the HyperNews system. HyperNews is a cross between the hypermedia of WWW and Usenet News. [13]. It allows the user to post articles in HTML as well as in plain text. An HTML article is presented by WWW browsers just as for other HTML documents. The user can see texts, pictures, and go to other WWW documents linked from the article. In addition to the main body of the article, HyperNews also presents links to the previous and next articles on the same topic.

One way to use the HyperNews is to store results of simulation. We made the user interface for simulation to allow the user to post the result of analysis with simulation parameters to the HyperNews. Members of the design team can share analysis results and find reasons for decision based on the result of simulation.

5. Conclusions

In this paper, we presented a knowledge centered approach to the design support of micromechanisms. SYSFUND has been shown to be capable of representing functional component of physical features for micro accelerometers. The user interface of the finite element analysis system allows a team of designers to share knowledge about building finite element models. HyperNews supports to share knowledge provided by the members of a design team. These tools are intended to support the designer to explore novel concepts in micro mechanisms design.

There are a few related studies dealing with the synthetic aspect of the micromechanism design. Nubbard and Antonsson reported an idea to generate a mask layout that produces the desired shape after etching[7]. Kota et al. are studying a synthesis methodology of micromechanisms [8]. These studies emphasize the use of knowledge for creating solutions.

A decision in an early stage of design may cause a great impact in the rest of design processes. Conceptual design is therefore the most important stage of design. For micromechanisms, however, conceptual design is not well practiced. Since micromechanism design is strongly restricted by the manufacturing technology today, there is
not much chance to think about alternatives for the same function. But we believe that the synthesis of available micro technologies will become one of the keys of micromechanism design in the future.

References