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Topology Optimization for Force Sensor Structure Considering Accuracy of Force Detection

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ABSTRACT

Multi-axis force sensors are extensively utilized in engineering fields, for example in automotive development, where 6-axis force transducers are used to measure force components applied to wheels, and as sensors in robotic manipulators. These sensors are composed of sensing devices such as strain gages and transducer structures. The transducer structures convert the forces applied to the measuring point of the sensor to strains, which are then detected by sensor devices. Each component of the applied forces can then be calculated, based on the acquired strain values.

The performance of multi-axis force sensors can be evaluated according to criteria such as the static and dynamic stiffness of the sensor structures, weight, strain gage sensitivity and force detection accuracy. Among these, the accuracy of force detection is often considered the most important performance, since it depends on minimization of force and strain sensing errors. In multi axis-force sensors, differences in the accuracy for each component of the applied force should be minimized. One well-known method for evaluating sensor performance is based on singular value decomposition [1], and represents the performance as a matrix condition number that expresses the relationship between applied forces and measured strains.

Although the theory of singular value decomposition is clear and has a well-developed mathematical foundation based on linear algebra, it is difficult to apply the methodology to the structural design of transducers. The theory is generally expressed in terms of control system performance, which gives little insight into the basic mechanics of target structures, so developing structural designs is time consuming and depends on trial and error processes. To avoid the need for such iterations and achieve high performance configurations, a number of structural optimization methods have been proposed [2]-[4],

but these methodologies are based on sizing or shape optimizations, and since these strongly depend on the quality of initial structural designs, novel high performance structural designs remain elusive.

On the other hand, topology optimization methods have been extensively applied to a variety of structural optimization problems, since Bendsøe and Kikuchi first proposed a so-called homogenization design method (HDM) [5], and they offer the greatest potential for exploring ideal and optimized structures because changes in topology as well as shape are allowed. The basic ideas consist of (1) the extension of a design domain to a fixed design domain, and (2) replacement the optimization problem with a material distribution problem. A homogenization method is used to deal with the extreme discontinuity of the material distribution and to provide material properties viewed in a global sense as homogenized properties. This method, called the HDM, has been applied to a variety of design problems.

Using this method as a basis, we develop a new structural optimization method for multi-axis force sensor structures considering the accuracy of force detection. First, we formulate the HDM in which continuous material distributions are assumed using a continuous interpolation function at each node [6]. Next, we clarify the mechanical requirements and design specifications of the sensor structure based on the methodology [1], and construct objective functions that aim to satisfy given design specifications. The sensitivity of the objective function with respect to the design variables that is required in the optimization procedure is formulated using the adjoint variable method. Based on these formulations, an optimization algorithm is constructed using sequential linear programming (SLP). Finally, we examine the characteristics of the optimization formulations and the generated optimal configurations and confirm the usefulness of our proposed methodology for the optimization of multi-axis force sensor structures.

REFERENCES

[1] M. Uchiyama, Y. Nakamura and K. Hakomori, “Evaluation of the robot force sensor structure using singular value decomposition”, *Advanced Robotics*, Vol. **5**(1), pp. 39-52, (1991).

[2] E. Bayo and J. R. Stubbe, “Six-axis Force Sensor Evaluation and a New Type of Optimal Frame Truss Design for Robotic Applications”, *Journal of Robotic Systems*, Vol. **6**(2), pp. 191-208, (1989).

[3] L. P. Chao and K. T. Chen, “Shape optimal design and force sensitivity evaluation of six-axis force sensors”, *Sensors and Actuators A*, Vol. **63**, pp.105-112, (1997).

[4] S. A. Liu and H. L. Tzo, “A novel six-component force sensor of good measurement isotropy and sensitivities”, *Sensors and Actuators A*, Vol. **100**, pp.223-230, (2002).

[5] M. P. Bendsøe and N. Kikuchi, “Generating optimal topologies in structural design using a homogenization method”, *Computer Methods in Applied Mechanics and Engineering*, Vol. **71**, pp.197–224, (1988).

[6] K. Matsui and K. Terada, “Continuous approximation of material distribution for topology optimization”, *International Journal for Numerical Methods in Engineering*, Vol. **59**, pp.1925–1944, (2004).