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主　論　文　の　要　旨

論文題目　**Development of A Built-in Sensor System Using Distributed Piezoelectric Polymer Film Sheets for Shear Strain and Stress Distribution Measurement of Soft Materials**
(柔軟素材のせん断ひずみおよび応力分布測定のための圧電ポリマーフィルム内蔵型センサシステムの開発)

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論　文　内　容　の　要　旨

The deformation and stress distribution inside a soft material, which is an important analysis index in the study of human-machine interaction, is hard to be estimated and observed using current interactive shear force sensors except for limited situations. The development of soft robotics enables unique measurements which rigid robots can not realize. In this regard, a sensor system applying piezoelectric Polyvinylidene fluoride (PVDF) polymer films, which are embedded in a soft material, was developed to measure the internal shear strain and stress. The overall objective of this doctoral research is the validation and evaluation of the measurement feasibility of the proposed built-in sensor system.

Chapter 1 introduces the research background, the relative studies, and the study objectives. The technical demand from human tissue safety assessment is increasing in the field of human-machine interaction. The observation of the distribution of the shear component of stress and strain is also a demanding technical difficulty. To overcome the spatial limitation of the traditional shear sensor, the compact and flexible PVDF polymer film is chosen as the built-in sensing element. This study aims to the establishment and validation of the sensing models and the evaluation of the feasibility and application of the proposed sensor system.

Chapter 2 explains the structure and the sensing methodology of the proposed sensor system. The design idea is to vertically arrange and embed the PVDF film sensor inside the soft substrate material. It takes advantage of the high flexibility and sensitivity of PVDF film to reflect the mechanical variations of the substrate. To explain the sensing mechanism, the shear strain and stress sensing models were mathematically established based on piezoelectricity and material mechanics. They provide a clear mathematical relationship between the signal output and shear variations. The "deflection-charge" transduction mechanism was newly established based on the electrical performance of piezoelectricity and mechanical behavior of a bending cantilever beam. Based on the electrical properties of PVDF film, a suitable charge amplifier circuit was designed for signal conditioning.

Chapter 3 describes the feasibility verification of the proposed sensing method. The measurement mechanism of shear strain distribution inside the substrate soft material is investigated. The sensitivity is reflected by detecting the shear strain distribution in the thickness direction and a three-dimensional field. At the same time, the applicable arrangement resolution of the PVDF elements is also evaluated. To verify the measurement principle, all the measured distribution results were evaluated whether the results agreed with the simulated results based on contact mechanics. The proposed sensor system could quantitatively visualize the three-dimensional shear strain distribution and measure the stress concentration state under different contact conditions of artificial skin. The proposed sensor system was confirmed to contribute as a new sensing method to the field of shape analysis. The sensor system can be applied to sufficiently sensitive dummy skin and can significantly contribute to skin damage analysis and skin contact safety assessment.

Chapter 4 focuses on the validation of the established sensing models based on the complex structure of composite materials. A bilayer structure of an artificial skin substrate was designed for the experiment to observe the possible application of the sensor system to more complex structures. For validation, the deflection of the embedded film sensors was monitored and digitized using a video camera in the experiments. The shear strain sensing model was validated by evaluating the agreement between the modeled and measured physical variations with a high coefficient of determination of 0.974. Based on the linear relation of arithmetic expression of each sensing model, the calibrated results for internal shear strain and stress sensing were also successfully obtained.

Chapter 5 is the application of the verified and validated sensor system to a dummy finger to simulate the skin tissue contact in the field of manufacturing. The dummy finger was manufactured according to the dimension and the mechanical properties of the human finger by the subject experiment. Two kinds of surface contact conditions, press, and press with slip are monitored and analyzed. The ability of shear strain measurement and slip detection of the sensor system inside the dummy finger was confirmed.

Finally, Chapter 6 summarizes the whole process of developing the sensor system and points out each experimental result in the above chapters. Successful development of the sensor system is expected to further contribute to the analysis of skin damage and the safety assessment of skin contact.