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Biological Signal Measurements for Automatic Driving System by PZT/PZT Sol-Gel Composite

Hiroto Makino, Kei Nakatsuma, Tomohiko Igasaki and Makiko Kobayashi
Graduate School of Science and Technology
Kumamoto University
Kumamoto, Japan
kobayashi@cs.kumamoto-u.ac.jp

***Abstract*— Automatic driving system will be overspread over the world in the near future and biological signal measurement of driver will be mandatory. High sensitivity piezoelectric sensors embedded in the car sheet could be one of the solutions. However, high signal to noise ratio (SNR) requirement of sensors is much demanded. Since the SNR of PVDF is low, development of new sensors for biological signal measurement has been desired. In this study, PZT/PZT piezoelectric film sensors were made by automatic spray coating method. 90µm thick PZT/PZT piezoelectric film ware fabricated on a 60µm thick stainless substrate by an automatic spray coating machine. Also, biological signal was measured by sensors embedded in the chair on two conditions of rest state and utterance state. Measurements by Electrocardiogram (ECG) and respiration sensor were also carried out simultaneously for comparison purpose. PZT/PZT piezoelectric sensors had higher SNR than PVDF sensor on rest state, so it peaks from pulse wave and respiration were clearly observed. The error rates of PZT/PZT sensors compared with ECG was lower than that of PVDF sensor. Also, in utterance state, peak intervals of and PZT/PZT piezoelectric film sensor were similar with R-R interval as well as rest state. However, clear peaks at regular intervals could not be confirmed from the signal obtained from PVDF sensor. From these results, PZT/PZT piezoelectric film sensors can monitor heart rate variability better than PVDF due to higher SNR.**

Keywords*— *automatic driving system; biological signal measurement; piezoelectric sensor; signal to noise ratio; automatic spray

I. INTRODUCTION

In recent years, automatic driving system has been actively developed around the world. If automated driving system is put into practical use, driver fatigue and stress will be greatly reduced. However, biological signal measurement of driver will be mandatory. High sensitivity piezoelectric sensors embedded in the car sheet could be one of the solutions. Measurement of biological signals by sitting on a chair with a sensor, it is possible to obtain stress-free heart rate variability without consciousness of the measurement itself. However, the signal to noise ratio (SNR) requirement of sensors is very demanded. Typical biological signal measurement, polyvinylidene difluoride (PVDF) sensors are used, even though SNR of PVDF is not high enough due to ringing effect. PVDF sensors cannot be used under high temperatures. Therefore, development of new sensors for biological signal measurement has been desired. Flexible sol-gel composite film sensor was developed for high temperature non-destructive testing applications [1]. Sol-gel composite was made from the mixture of ferroelectric powders and dielectric sol-gel solution and flexibility was accomplished due to the porosity existed in the piezoelectric film. Sol-gel composite piezoelectric film sensor has high SNR and high sensitivity for movement so that it was expected that it was possible to measure biological signal. In the past study, $Pb(Zr,Ti)O_3$ (PZT)/PZT piezoelectric film sensors, which were made by PZT powders and PZT sol-gel solution, succeeded in pulse wave measurement from the wrist [2]. However, it is not practical to ask the drivers to wear wrist band. In the previous study, biological signal was measured by sensors embedded in the chair under resting conditions and measurements by electrocardiogram (ECG) and respiration sensor were also carried out simultaneously for comparison purpose [3]. As a result, PZT/PZT sensors has lower error rate than PVDF sensors concerning R-R interval measurement. In addition, PZT/PZT sensors could observe respiration curves which PVDF sensors could not detect. In this study, biological signal measurements were carried out under speaking conditions to simulate real conditions.

II. SENSOR FABRICATION

PZT/PZT sol-gel composite sensors were made by sol-gel spray technique. First, PZT powders and PZT sol-gel solution were prepared. PZT sol-gel solutions was self-manufactured. PZT powders were chosen because of raw material availability, high sensitivity, and poling facility [1-3]. The mixture of PZT powders and PZT sol-gel solution was ball milled. Then, the mixture was sprayed onto a stainless substrate by an automatic spray coating machine. The thickness of stainless substrate was 60µm. This substrate was chosen due to appropriate hardness and high temperature durability. After spray coating, drying at 80°C on a hot plate, 150°C in an electrical oven and firing at 650°C in an electrical furnace was processed for 5 min each. Those spray coating process and thermal process were repeated until film thickness reached 90µm. After film fabrication, poling was operated by positive corona discharge at room temperature. The distance between the tip of the discharge and the piezoelectric film on the substrate was about 1.5cm. After these processes, thin silver top electrodes were manufactured using silver paste. Finally, electrical connections were assembled to serve as biological sensor. Optical image of PZT/PZT piezoelectric film sensor onto stainless substrate is shown in Fig. 1.

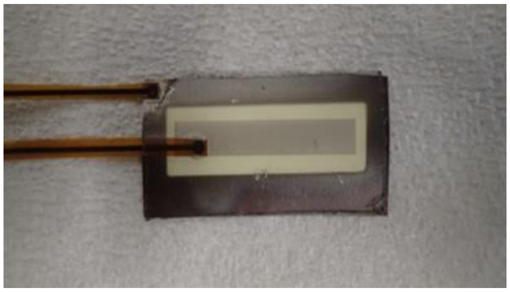

Fig. 1. Optical image of PZT/PZT piezoelectric film sensor.

III. EXPERIMENT SETUP

Biological signal was measured by sitting on a chair with PZT/PZT piezoelectric film sensors and PVDF sensors. ECG by the sensors attached to subclavian and abdomen and respiration by abdominal circumference respiration sensor were measured simultaneously for comparison purpose. In the previous study, measurement for 5 minutes was carried out at rest state that does not suppress breathing [3]. The piezoelectric sensor layout is shown in Fig. 2. Two PZT/PZT piezoelectric film sensors were taped onto the middle of wooden chair side by side near one of the PVDF sensors.

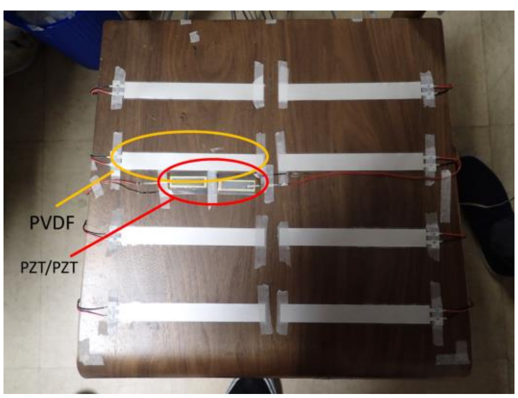

Fig. 2. The previous layout of PZT/PZT and PVDF sensors.

In this study, measurement was performed for 5 minutes on utterance state, which are more real situations. The piezoelectric sensor layout is shown in Fig. 3. PZT/PZT piezoelectric film sensors were placed adjacent to PVDF sensors onto rubber rug placed on a chair. In addition, in order to measure more efficiently, the placement is changed. PVDF sensor 1, 2 and the PZT/PZT piezoelectric film sensor 1, 2 are intended to measure the buttocks, and the PVDF 3, 4 and the PZT/PZT piezoelectric film sensor 3, 4 are intended to measure the femur. 10Hz low pass filter was used for PZT/PZT and PVDF sensors. Signals obtained from the PZT/PZT piezoelectric film sensors and PVDF sensors are processed with a 10 Hz low pass filter without an amplifier, and signals obtained from the ECG and the respiration sensor are amplified by an amplifier, and processed with a 40 Hz and 30 Hz low-pass filter, respectively. The measurement results were recorded by a digital oscilloscope.

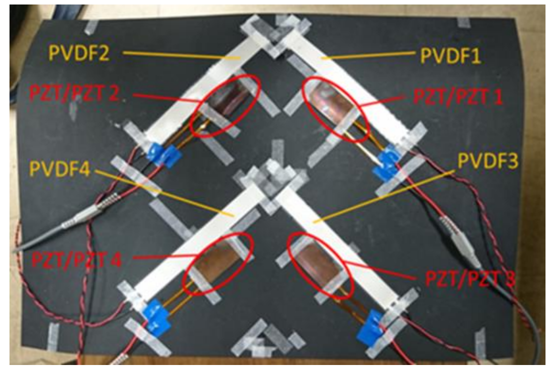

Fig. 3. The modified layout of PZT/PZT and PVDF sensors.

IV. EXPERIMENT RESULTS

Fig. 4 shows typical measurement results by PVDF sensors, PZT/PZT piezoelectric film sensors and ECG. From Fig. 4, peak intervals of PZT/PZT piezoelectric film sensor were similar with R-R interval as well as rest state. However, clear peaks at regular intervals could not be confirmed from the signal obtained from PVDF sensor, and peaks derived from pulse waves could not be confirmed. It is presumed that this is because a high frequency component such as body movement due to speech is cut by damping by micro porous of the PZT/PZT piezoelectric film.

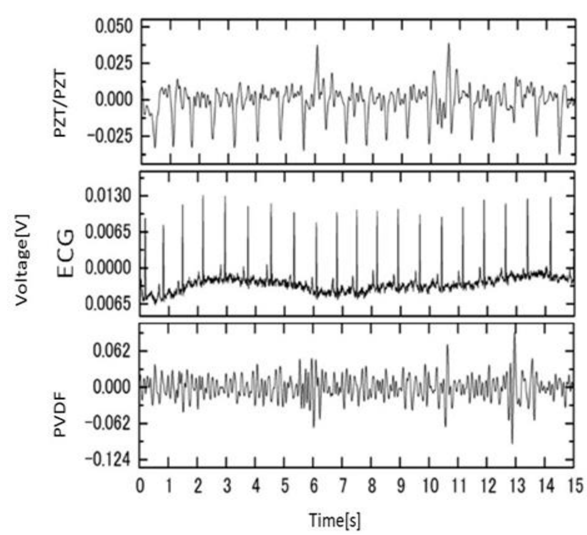

Fig. 4. Measurement result of PVDF sensor, PZT/PZT sensor and ECG at utterance state.

V. CONCLUSION

90μm thick PZT/PZT piezoelectric films were fabricated on a 60μm thick stainless substrate by an automatic spray coating machine for biological signal measurement under speaking conditions. Biological signal was measured by PZT/PZT and PVDF sensors embedded in the chair and ECG. Measurement was performed for 5 minutes on utterance state. As a result, peak intervals of PZT/PZT piezoelectric film sensor were similar with R-R intervals as well as rest state in the previous study, whereas no clear peaks at regular interval was confirmed by PVDF sensors. From these results, PZT/PZT piezoelectric film sensors can monitor heart rate variability better than PVDF due to higher SNR in addition to thermal durability.

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