博士論文　(要約)

A multiple threshold MEMS shock sensor for ultra-low power surveillance
(極超低消費電力監視のための多段しきい値 MEMS ショックセンサ)

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指導教官　三田　吉郎　准教授

東京大学大学院工学系研究科
電気系工学専攻

37-167300
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(Ranga Reddygari, Ranga Reddy)

Within the past few decades, there has been rapid advancement of technology towards Internet of Things (IoT) and industrial applications mainly for consumer safety and security and in a recent report it is mentioned by 2020 around 40-50 billion devices connected through IoT. Health monitoring of these systems/devices is very crucial during their operation to predict their performance and also for preventive maintenance. Impact/shock is one of the critical damaged induce mechanism during their operation which can severely influence the performance of the system.

For these types of applications, various micro-electromechanical (MEMS) accelerometers, and vibration/shock sensors utilizing different actuation and sensing mechanisms have been demonstrated. By using MEMS technology these devices have been successfully developed and commercialized, however, the power consumption in these MEMS accelerometers is still a major problem especially for a long term and remote monitoring applications where power supply is severely limited. In most cases for MEMS accelerometers, the large power consumption is attributed to the analog front end needed for reading, processing, and analog to digital conversion of the sensor output, which is typically responsible for most to all the power consumption of the whole sensor. And also, these conventional accelerometers always to be turned on even when there is no impact acceleration acting on the system. This research dissertation focuses on developing a new class of MEMS accelerometers allowing significant power reduction by eliminating the need for the analog front-end and requirement of continuous power during their operation.

Latching shock sensors are one type of acceleration threshold sensors that trigger when the acceleration level exceeds the preset threshold value. The latching mechanism provides a mechanical memory, which keeps the sensor in a triggered, or latched, state until the sensor is reset. The attractive feature of this type of sensor is that it does not require power during monitoring; power is only needed to query and reset the sensor. However, reported devices in the literature have limited operable range and resolution, can detect only 1 or 2 threshold events, and most of the devices are not reusable that means often replacement and additional human effort is required.

This dissertation presents the design, modeling, fabrication, and testing of a new novel threshold shock sensor that can detect and store multiple threshold events (or physical off-limit conditions) with robust latching mechanism using mass-spring assembly. The latching part on a seismic mass enables the discrete latch positions depending on the applied external impact forces and stores the impact value over a long period of time without any external power supply. An electrostatic actuator is incorporated for reinitializing the device by releasing coupling between the latching parts for reusability.

Firstly, a detailed numerical model has been developed to predict the device behavior for a given impact acceleration by considering different forces acting on the system, which can help to design new novel devices using latching mechanism for different applications, and also on-chip test structures have been developed to understand the frictional behavior of latch coupling parts while in contact for different DRIE process parameters. Threshold shock sensors have been designed and developed on silicon on Insulator (SOI) wafer using standard MEMS fabrication process.

The fabricated shock sensors were investigated over a wide shock range by using an impact test setup and the experimental results were verified with the developed model. And also, the numerical model predictions are validated the experimental results through a quantitative comparison of the proof mass behavior during latching events captured via high-speed videography. Finally, Various readout schemes have been adopted to deploy the proposed zero power shock sensor towards IoT/ultra-low power surveillance applications where it can significantly increase the device performance by reducing the amount of power consumption required during their operation.

In summary, a zero-power shock sensor for detecting multiple threshold events over a wide range with reset capability is designed, fabricated and validated with the developed model. Having high reliability, optimum resolution and reusability makes the device more suitable for different low power applications varying from IoT to consumer and industry safety applications and also it can be used as a long-term memory storage device.