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Non-electrical sensing and storing an alternative to electrical energy harvesting

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Abstract

In many applications, a summarized result, e.g. the number of critical off-limit conditions or an integral result over a specific period of time are of interest to draw implications for the future. Among these applications are the shelf life monitoring of consumables, pharmaceutics or food as well as the condition monitoring of technical infrastructure. Sensors usually require an electrical energy source for measurement and storage of data. Here, two non-electrical examples are presented that register data without the need of electrical energy: a passive temperature-time integrator (TTI) and a mechanical binary counter for threshold events. The TTI makes use of microfluidic flow of specific food ingredients into microcapillaries that depends on viscosity and time. The binary counter based on surface MEMS allows counting and storing threshold events, e.g. mechanical shocks. Both sensors can easily be read out e.g. by RFID.

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Keywords: non-electrical, temperature-time-integral; ratchet; binary counter; off-limit condition; sensor; MEMS; microsystem

1. Introduction

The efficient use of resources is one of the key global challenges today. Tremendous amounts of food and other valuable but perishable goods are discarded already within the logistic chain. Improving sensory control during the logistic chain would help to identify the actual residual shelf life beyond an expiration date and allow an efficient use of resources. On the other hand, in complex technical systems the maintenance is often based on empirical data,

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only. Condition monitoring can help to select the required maintenance and thus to reduce costs and resources. In both cases, sweeping information from a period of time is required, only.

So summarized results of critical off-limit conditions or integrals of a parameter within the preceding period are sufficient to draw implications for the future, e.g. the need for extended maintenance or an estimation of remaining shelf life or product quality. Physical parameters of interest could be maximum or minimum values as well as integrals or the number of off-limit conditions within a characteristic period of time (see fig.1). Preferred solutions for long-term monitoring should be autonomous systems. Usually these systems require an electrical energy source such as an electrochemical storage or an energy harvester that require further resources and often contain critical chemicals. Energy harvesting is still expensive and is suitable for a small range of applications, only, and chemicals as used in batteries cause sensitive waste.

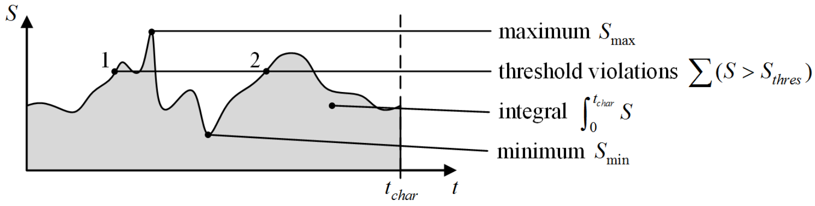

Fig. 1. Retrospective information of interest from a measure S that requires non-electrical sensing and storage.

Here, two non-electrical sensor concepts for condition monitoring for supervision within logistics on item level or extended preventive maintenance have been chosen: A non-electrical temperature-time-integrator and a mechanical binary counter for threshold violations are exemplary presented. Both systems do not require electrical energy for detection and storing of the respective physical condition. The detected values are stored over an arbitrary long period of time. Additionally, the storage allows for an electrical read-out (e.g. via RFID) at any time.

2. Temperature-Time-Integrator

The temperature-time integral is a crucial quantity for perishables that usually degrade faster with rising temperatures. Commonly used expiration dates presume that the intended storage conditions are met during the complete logistic chain, but this cannot be guaranteed. For this reason, the expiration date is usually a cautious forecast. A real-time control on item level requires a cheap and simple solution that contains non-toxic ingredients, only.

Here, the progressive filling of a microcapillary with a fluid is used as a non-electrical integrator. The flow into the capillary strongly depends on the temperature-dependent viscosity of the fluid. Figure 2 shows a fabricated microsystem demonstrator and the respective system combined with an RFID. In this case, a programmable RFID demonstrator is used and the microchannels are manufactured by microsystems technology. For a mass production, these channels can also be realized within the packaging material, e.g. during hot embossing and sealing of the packaging materials. The fluid is selected from food ingredients for two main reasons: they are definitely non-toxic and the change of their properties with temperature is a suitable measure for the aging of food.

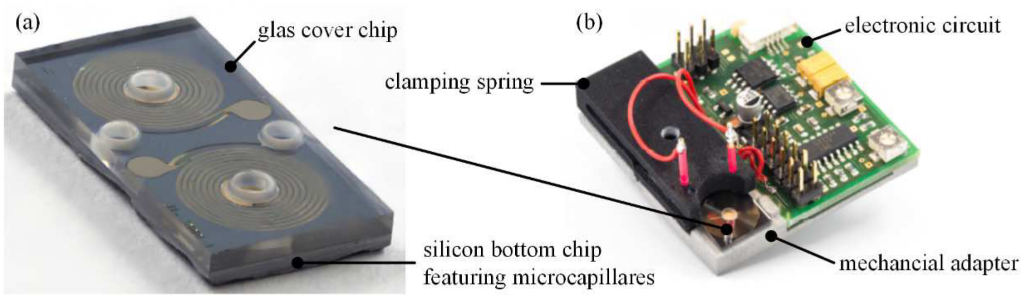

Fig. 2. (a) Fabricated microfluidic chip (focus stacked picture); (b) microsystem demonstrator for RFID measurement.

For a first demonstrator, standard MEMS technologies have been used. The microcapillaries are etched into a silicon chip. Both the capillary chip and a glass cover feature a metallic conductive path along the capillary. Holes are laser drilled into the glass chip for the electrical connection and as a fluid reservoir. The two conductor paths form a capacitor. If the temperature increases, the filling of the microcapillary progresses and the fluid causes a change of capacity due to its dielectric constant. Here, polar liquids with higher dielectric constant such as sugars are preferred. The filling continues permanently but depends strongly on the actual temperature. Therefore the capillary capacitor forms the non-electrical storage of the temperature-time-integral.
Electrical energy is necessary for electrical read-out, only. A wireless RFID-based demonstrator based on commercial RFID equipment was designed (see fig. 2b) for read-out. The test setup and the measurement result are shown in figure 3. As the dielectric constant of the chosen fluid strongly depends on the temperature, a differential measurement using two capacitors next to each other is needed (see fig 2a). The measured capacity is compared to the visible filling. The signal follows a root function and delivers in contrast to the TTI in [1] a continuous signal.

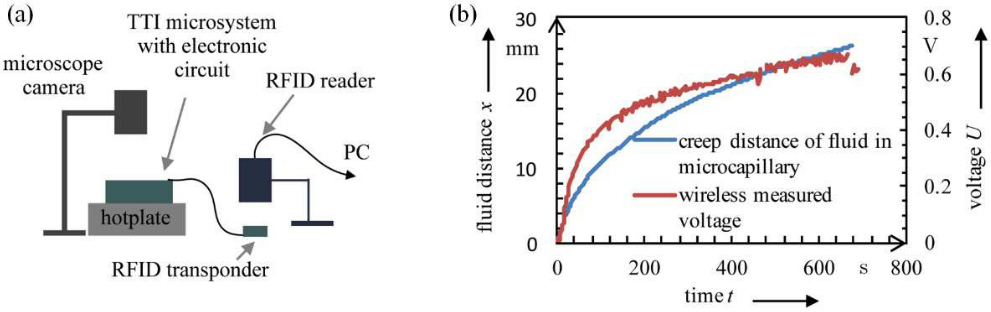

Fig. 3. (a) Test setup used for system characterization (b) measurement results – electrical read-out compared to creep distance of the fluid measured optically

3. Binary Counter

For preventive maintenance, the detection and storing of the number of critical off-limit conditions (e.g. mechanical shocks) could be extremely helpful to call attention to the requirement of an extended service. A binary counter mechanism (see fig. 4) has been fabricated in surface MEMS that enables detection and storing a number of impulses that are caused by off-limit conditions as a mechanical binary code [2]. Input transducers are under investigation.

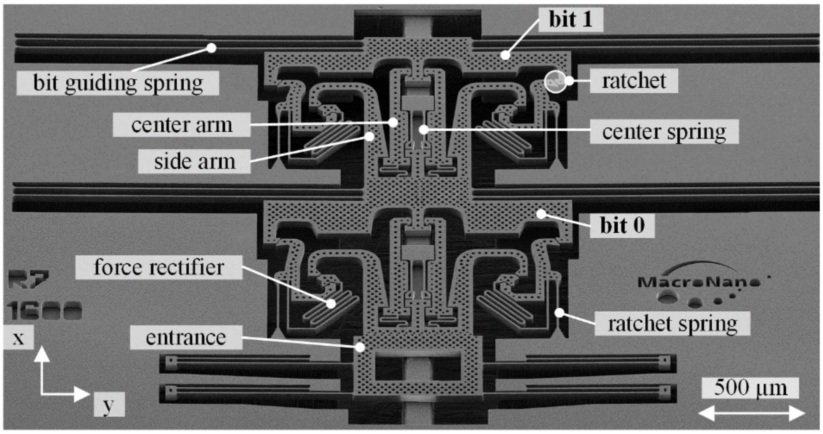

Fig. 4. SEM picture of a fabricated 2-bit binary counter – essential system components are shown – both bits are in the *high* state.

Adapting the idea of an electronic shift register, a micromechanical counter mechanism is designed. A switching energy released by the off-limit condition acts on the spring-guided entrance. This causes a movement of several mechanical coupling elements in a way that serially arranged elements – referred as bits – change their position between two stable positions; the *high* state (1) and the *low* state (0). The position of all bits represents the current counter value in binary code. Hence, the system needs non-electrical input energy for counting, only.

An event is a physical quantity such as temperature, pressure or acceleration, with an energy larger than a critical threshold. The mechanism is suitable for counting any physical event that can be converted into an adequate force-travel characteristic. The number of detectable events is limited by the number of serially arranged bits, only. The necessary force and mechanical energy for counting from 0 to 3 utilizing a 2-bit demonstrator are shown in fig. 5.

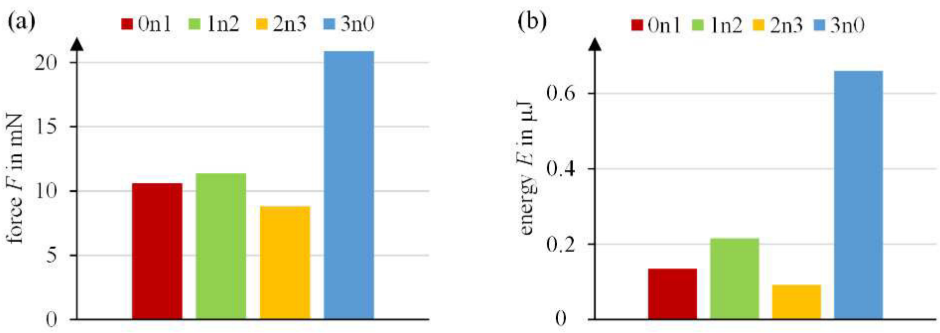

Fig. 5. (a) Forces and (b) input energy for counting from 0 to 3 utilizing a 2-bit system

Binary counting implements the analogue-digital conversion by a mechanical system so a direct broadcast (e.g. via RFID) of a digital code is enabled. The system design can be expanded towards an electrical read-out of the bit positions by measuring whether the bit guiding springs are strained or unstrained. Moreover, expanding the design to e.g. up to ten bits would result in a counter mechanism able to store 1023 off-limit conditions. As the switching energy scales almost linearly with the number of bits, this system would need a peak energy of around 3.6 µJ at the entrance. A further reduction of this energy as well as a downsizing of the counter are under progress.

4. Summary

Non-electrical sensing and storing is a suitable alternative to energy harvesting. It allows to control the history of goods and technical equipment over a long period of time. Nevertheless the read out can be done wireless e.g. by RFID. Large numbers of single items as well as sensors placed inside a package or a housing can be checked easily. As a first sample, a temperature-time integrator is demonstrated that is based on the viscosity-dependent capillary flow of food ingredients. For this reason, it is also well suited for consumer packages whereas a mechanical binary counter is designed for the support of maintenance in industrial goods.

Both sensors are samples for a new class of sensors with non-electrical transducer and memory. They are optimized for wireless RFID read-out, low cost and suitable for item level application.

Acknowledgements

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