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Abstract

Energy-Autonomous Tread Wear Wireless Sensor System for Tire Monitoring †

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Abstract: Technologies are going through a digitalization process. Convergence of 2D printing with 3D printing is leading to 3D structural electronics. Implementation during their fabrication of sensing components in objects using printing would make these 3D-printed objects smarter. At the same time, sensors production would benefit, thanks to their digital manufacturing in the 3rd dimension, from customization, self-packaging, and better integration into products. We are proposing to apply digital printing of functional and structural inks addressing the challenges of the whole processing in a single tool. Developments in the field of smart wearables are presented.

Keywords: autonomous; energy harvesting; sensors; tire monitoring; tread wear; wireless

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1. Introduction

In this communication, we report on a study performed to design a self-contained tread wear sensor node for an automobile tire (for either passenger vehicles or trucks). The node is to be inserted into the tire and function autonomously using energy harvested from the motion of the wheel. The sensor embedded in the surface of the tire measures the degradation of the tread over time and wirelessly communicates the measurements periodically to an existing onboard system in the automobile. For safety reasons, the tread depth on the tires of a vehicle must be greater than a legal defined minimum, which depends on the type of tire and the vehicle (e.g., 2 mm for summer tires and 4 mm for winter tires on a passenger vehicle). The minimum tread depth is required in order to maintain an adequate amount of traction between the tire and the surface of the road. Therefore, it is important that the operator of the vehicle is aware of the tread depth on the tires of the vehicle. At present, several mechanical systems based on needles and gauges, and even optical-based sensor systems, are commercially available and commonly used to measure the tread depth of tires. Unfortunately, all of the present tread-depth measurement techniques exist as off-board systems.

2. Materials and Methods

A concept for the full system architecture of a wireless sensor node to be inserted into the tread of an automobile tire has been developed, as shown in Figure 1. Tread-wear sensing element prototypes were designed and printed on foil. Electronic circuitry for sensor read-out and power management was designed. The most appropriate communication strategy considering the available communication protocols was determined. The energy budget and measurement and communication duty cycle of the wireless sensor node were estimated. Two piezoelectric energy harvesters based on the tire vibration and compression, respectively, were devised to satisfy the energy budget. Their robust packaging to withstand high shocks was addressed.

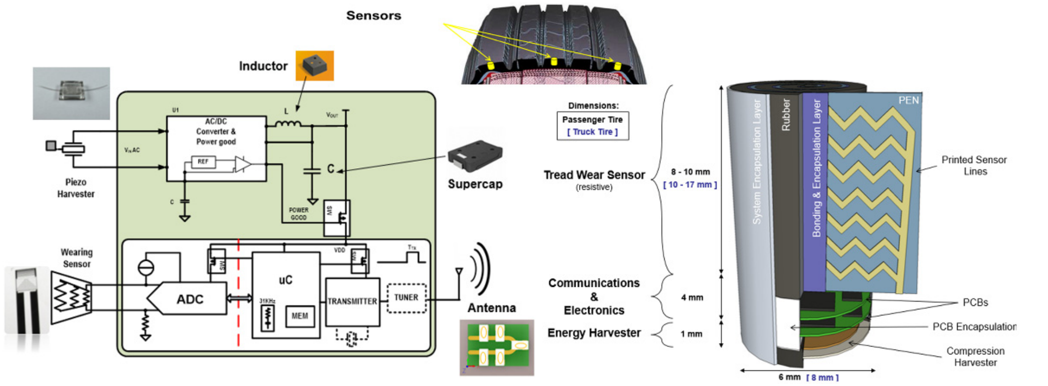

Figure 1. The full system architecture of the tread wear wireless sensor node and position in the tire.

The dimensions of the node are given by the approximate dimensions of an insertable tire stud for a passenger (or truck) tire. A resistive sensor, which wears at the same rate as the tread, is placed at the top of the sensor node in contact with the surface of the road. Multiple levels of electronics required for power management and wireless communication are placed just below the sensor in a protective package. Below the electronics is an energy harvester which provides the energy required by the read-out electronics of the sensor and wirelessly transmits the data to a nearby receiver. Since the tread wear on tires is gradual, a high data transmission rate is not necessary.

3. Results and Discussion

Different components of the system are presented in Figure 2. In regard to the sensor and electronics, the energy budget, and wireless communication, the analysis and tests have shown the feasibility of the tread wear wireless sensor node. With respect to the energy budget, assuming a harvested current of 4 μA at a voltage of 4 V (a continuous power of 16 μW), it is deemed to be achievable with the direct force energy harvester. Storing the energy in a low leakage SMD capacitor, the first transmission rate will occur after approximately 32 min and 45 min for RKE and BTLE protocols, respectively, at a speed of 100 km/h. From the antenna loss measurements, the impact of the rubber in the tire was found to be negligible. Based on the results obtained from tests performed on a car, both communication technologies (433 MHz and 2.45 GHz) have been deemed feasible for the sensor node. From this feasibility study, we have found that the restrictive dimensions of the given application present a challenge, especially for the antenna design. Custom ASICs and bare silicon dies will be required to satisfy the spatial requirements of the sensor node. The concepts must be tested with real-life conditions in order to determine the percentage of energy lost when moving between a laboratory environment and real conditions.

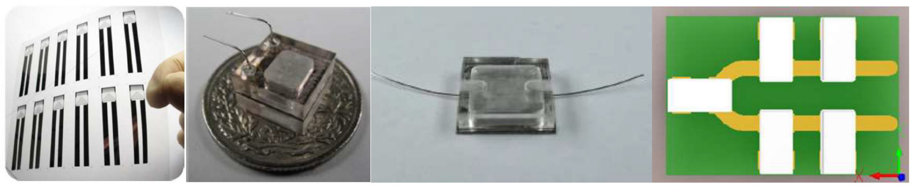

Figure 2. Prototypes of the different components developed and evaluated, from left to right: wear sensors, packaged PVDF vibration and PZT compression energy harvesters, 434 MHz antenna.

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