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Energy harvesting and strain sensing in smart tire for next generation autonomous vehicles

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HIGHLIGHTS

- Developed high energy density harvester-cum-sensor to power wireless data transfer.
- The generated energy from tire strain harvester was enough to directly power 78 LEDs.
- A mathematical model for tire-road interaction and piezoelectric response.
- Real environment test for sensing tire-road interaction under different variables.
- Demonstrated the self-powered smart tire sensor for autonomous vehicles.

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ABSTRACT

We demonstrate the feasibility of the strain energy harvesting from the automobile tires, powering wireless data transfer with enhanced frame rates, and self-powered strain sensing. For this, we used a flexible organic piezoelectric material for continuous power generation and monitoring of the variable strain experienced by a tire under different driving conditions. Power output of ~580 μW at 16 Hz (~112 km/h) from the energy-harvester and mounted on a section of a tire, is sufficient to power 78 LEDs. We further demonstrate that the stored energy was sufficient to power the wireless system that transmits tire deformation data with an enhanced frame rate to control system of a vehicle. Using sensors mounted on a tire of a mobile test rig, measurements were conducted on different terrains with varying normal loads and speeds to quantify the sensitivity and self-powered sensing operation. These results provide a foundation for self-powered real-time sensing and energy efficient data transfer in autonomous vehicles.

1. Introduction

In autonomous vehicles, energy requirement has been increasing rapidly with the increased number of onboard sensors, and the requirement for an increased rate of wireless data transfer for safe and reliable driving. There is tremendous development taking place in both academia and industry to provide devices, systems, and techniques [1,2] that lead to energy efficient self-governing automobile environment [3,4]. For automobiles, tires act as an interface between the vehicle control system and the external environment. The abundant vibration and strain energy in a rolling tire can be used for energy harvesting to power wireless sensors [5]. This is especially important

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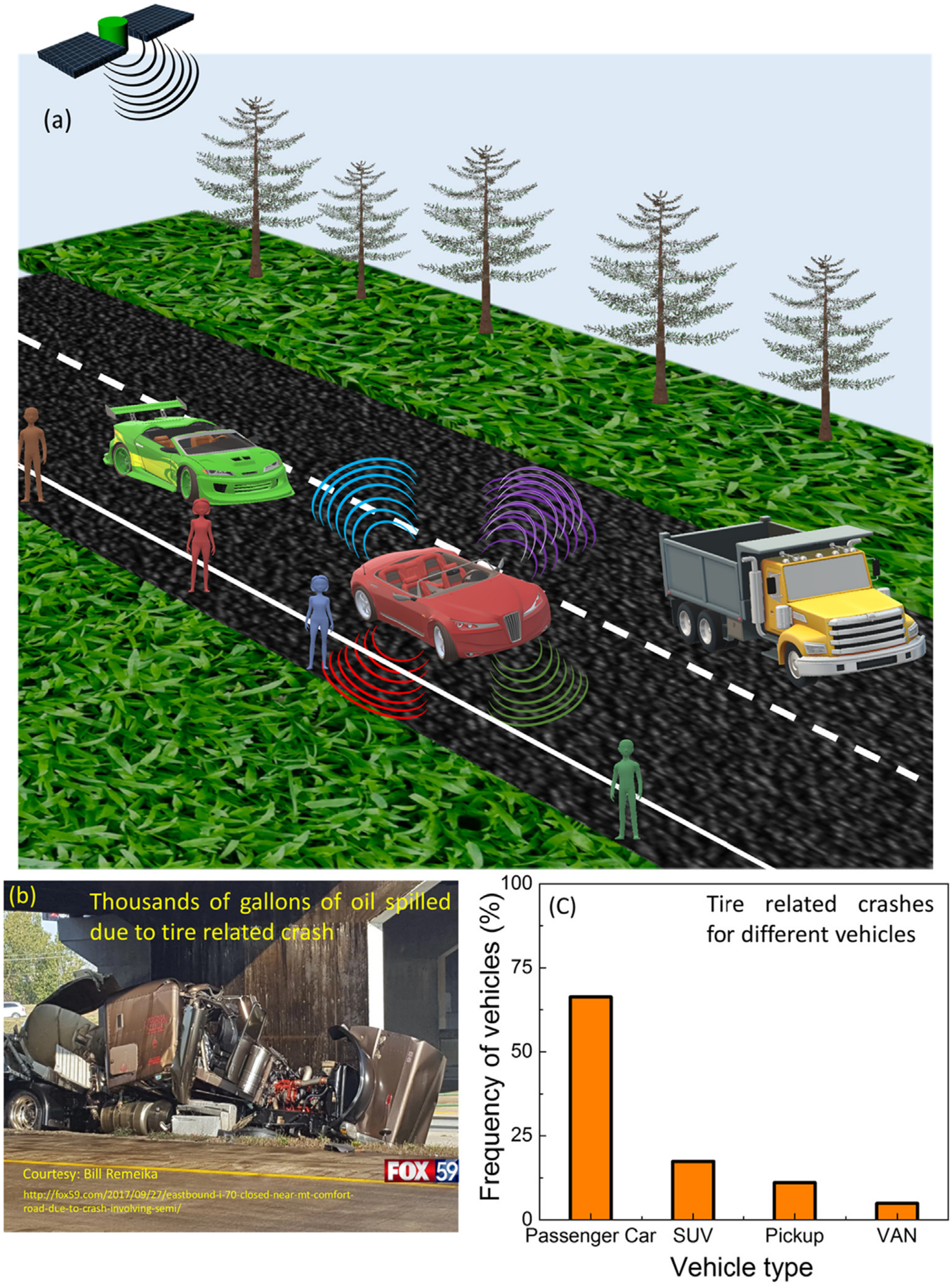

Fig. 1. (a) Schematic of an autonomous vehicle on the road. (b) Oil spill due to a flat tire-related accident causing serious environmental threat. (c) The distribution (%) of tire-related crash vehicles including their types. (Source: U.S. Department of Transportation, National Highway Traffic Safety Administration).

considering the increasing length of the wires with the number of sensors in modern cars, which further increases weight of the vehicle, needs more space, and reduces vehicle's reliability [6]. Such energy harvesting solutions will ultimately reduce the load on the vehicles's main battery, thereby, increasing the efficiency of the vehicle. In order to achieve tire-based self-powered sensing of the external environment and wireless data transfer, recent focus has been on developing smart tires with energy generation capability [7,8]. The sensor arrays, in smart tires, are used for monitoring and evaluating different physical quantities such as road/terrain characteristics, air pressure, road/tire friction, loadings, wear, and hydroplaning [9]. These quantities are then used by intelligent algorithms for enhancing the consistency, longevity, safety, stability and fuel efficiency of a vehicle [7,10,11]. The smart tires equipped with the efficient energy harvesting systems, are not only beneficial for the autonomous cars (Fig. 1(a)), but, also will be helpful in controlling tire-related crashes in traditional vehicles. The tire-related crashes can be extremely deadly, and sometimes highly damaging to the environment, as shown in Fig. 1(b). According to a report [12], out of the total number of crashes, the tire-related crashes were approximately 6%, 4.6%, 4.3%, and 3.5% for passenger cars, SUVs, pickups, and vans, respectively. Among different kinds of vehicles, the tire-related crashes (as shown in Fig. 1(c)) were highest for the light passenger car (66.3%), which was followed by SUVs (17.4%), pickups (11.1%), and vans (4.9%). Therefore, developing an energy efficient smart tire has been one of the important aspects in achieving fully autonomous vehicles. Global initiatives such as European Union project APOLLO (2003) and Bridgestone/Firestone recall helped to fuel the momentum of intelligent and energy efficienct tire development in