

# Smart tire system concept

A new tire monitoring system promises to improve safety for future vehicles

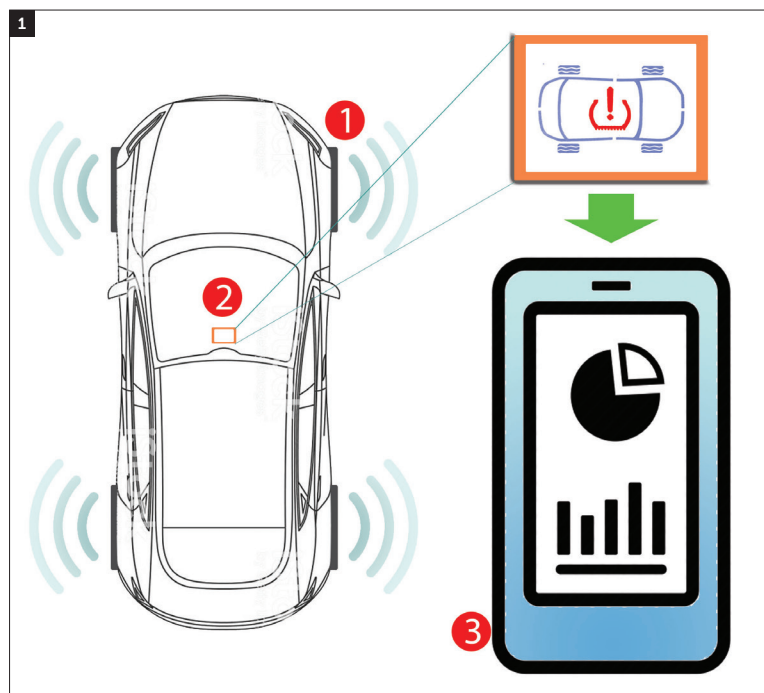
by Amirhossein Shahdadi, Sharif University of Technology; Afshin Ashofteh, University of Tehran; Mahsa Nematollahi, Amirkabir University of Technology; and Mahdi Akbari, University of Tehran, on the behalf of Barez Industrial Group Innovation Center

The focus on improving the active safety of transportation, coupled with the emergence of concepts such as the Internet of Things (IoT), has driven the tire industry to produce smart tires. IoT is rapidly making headway into most consumer products. In practice, this means that objects are equipped with sensors that can measure, identify and react to changes in the environment. Smart tires incorporate a variety of sensors and continuously evaluate parameters such as pressure and temperature.

For example, an increase in the internal temperature or pressure may be an early indication of tire damage, allowing this to be addressed before it causes a dangerous situation on the road. The sensors constantly monitor the performance of the tire and send information to the driver. When the information received from tires is combined with other sources, such as weather data, a vehicle's onboard information system can form a picture of the prevailing driving conditions and inform the driver accordingly.

Tires are the only interface between the vehicle and pavement; thus they play a primary role in vehicle safety. Estimating reliable tire parameters is important because the tire's performance is directly linked to that of the vehicle and the safety of driver and passengers. Various reports<sup>1,2,3</sup> show that adverse road conditions and tire defects play a major role in road traffic accidents. As a consequence, there is an urgent need, from a traffic safety point of view, for a smart tire with a warning system for road conditions, optimizing control on poor surfaces, and a tire defect detection system that measures tire deformation. Surveying the literature shows that numerous studies have focused on the application of smart tires because this technology is believed to

Figure 1: General layout of the Barez smart tire concept, with 1) sensor package, 2) control unit and 3) smartphone app



provide more accurate data about tire variables of interest using sensors that are installed within or inside the tire.

As one of the first in this field, a European Union project called APOLLO has been set up to develop smart tires capable of monitoring deformation.<sup>1,4</sup> Tire deformation or strain monitoring can be used to deduce the amount of friction between the tires and road surface, which can then be used for the optimization of automobile tire control systems, such as ABS.

Recently, research into smart tires has increased considerably. Much work has been done in the USA, Japan and Germany.<sup>5,6</sup> Considering different values exploited from smart tires, various parameters such as contact length, hydroplaning portion, longitudinal and lateral forces, friction and slip angle can be estimated using appropriate sensors.

Among these parameters, temperature and pressure are the most important, due to their direct effects on vehicle control and thus safety. A literature review shows that different research groups have

addressed this issue. According to the statistics, 30% of traffic accidents in China were caused by tire issues. In addition, 75% of all flat tires were caused by insufficient running pressure or a gradual loss of pressure over time. Furthermore, if tire pressures are not correct, rolling resistance, fuel consumption and tire abrasion are increased and the tire's service life is decreased.

A 10% drop in pressure cuts a tire's service life by 15%. Also, for each fall of 0.21 bar under correct tire pressure, fuel consumption is increased by 1.5%. Smart tires can check the pressures automatically and alert the driver when pressures are abnormal. Zhang et al<sup>7</sup> described the structure and principle of a smart tire measuring the pressure and temperature based on wireless passive surface acoustic wave (SAW) sensors. In another study, Schimetta<sup>8</sup> presented a passive pressure and temperature sensor unit based on a combination of SAW and capacitive pressure sensors.

In this paper, the development process of the smart tire by the

Barez Industrial Group is explained. This new technology is able to measure pressure, temperature and mileage of the tire, and establishes a communication between the driver, the tire and the vehicle.

The Barez smart tire has three main components: a sensor package inside the tire, a control unit in the vehicle and a smartphone application. The paper will discuss the types of sensors and the corresponding measurement values for application in the smart tire system. It will also detail the development procedure undertaken by the Barez Industrial Group and draw conclusions.

### Types of sensors

For the purpose of detecting different tire parameters, various kinds of sensors are used. These sensors cannot be inserted into a tire's structure due to the severe relative movement between tire components. Thus, the sensors generally are attached to the tire innerliner.

Accelerometers based on microelectromechanical systems (MEMS) are widely used. This type of sensor ensures signal linearity and stability over time, and insensitivity to temperature change.<sup>9</sup> Due to these characteristics, accelerometers are highly desirable for installation into tires.

Various kinds of strain sensors have also been developed, using different measuring principles, to estimate the strains in the contact patch of a rolling tire. Among these sensors, piezoelectric material, such as polyvinylidene fluoride, has been largely adopted to measure the

strain.<sup>10</sup> These sensors provide high flexibility and strong compatibility with rubber.

Another type of strain sensor utilizes the SAW device. This device consists of a piezoelectric substrate with metallic structure, such as an interdigital transducer (IDT) as a sensor element for measuring physical quantities, coupled with a local radio transceiver. SAW-based sensors are fully passive without requiring a power supply and thus are ideal for wireless communication; however, it is difficult to install multiple SAW sensors in a single tire due to their operational fundamentals. SAW-based sensors can be used to measure the deformation of tread and estimate the friction.<sup>11</sup>

It must be mentioned here that strain sensors are preferred to accelerometers since they can be directly related to tire deflection and operational conditions. Also, the signal noise level of strain sensors is generally lower than that of accelerometers, and the measured value is not affected by the tire rotational speed.<sup>1</sup>

To monitor the global deflection of the tire, optical sensors have also been frequently used.<sup>1</sup> In these systems, an LED is attached to the tire innerliner and its light focused on a position detector on the rim through a lens. It is seen that an optical sensor is the best choice to estimate the wheel force to a good degree of accuracy.<sup>2</sup> Besides the optical sensor, ultrasonic distance sensors are also utilized to measure the vertical deformation of a loaded rolling tire. These sensors are

Figure 2: The main components of the Barez smart tire, including 1) sensor package, 2) control unit and 3) smartphone application (note that in this figure, only one sensor has been connected to the control unit)



mounted on the base of the wheel and measure the distance from the sensor to the opposite inner wall of the tire.<sup>12</sup> In addition, the temperature inside the tire can be calculated, based on time of flight, as this is a function of temperature.

Sensors used to monitor tires include passive and active types. A drawback of passive sensors is that they require a separately implemented data acquisition system. In contrast, active sensors are more expensive but more appropriate for smart tires. Active-type sensors need a power supply, which is usually a battery. The drawback of batteries is that they have to be replaced. Therefore, the concept of energy harvesting has received increased attention recently. This technology is an interesting way of capturing a portion of energy that is being wasted in tires due to heat and vibration.<sup>13</sup>

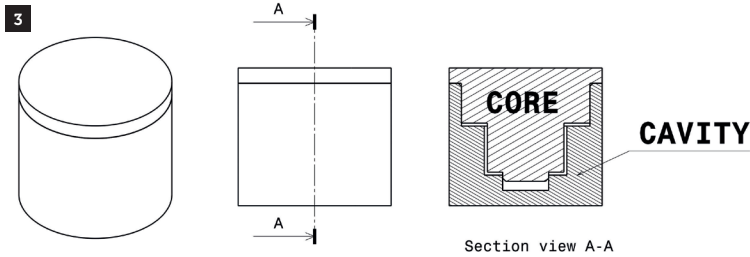
### The Barez smart tire

The tire industry has already taken the first steps toward smart tires, and sensors are already commonly used for measuring different tire parameters. As the most prestigious tire company in the Middle East, the Barez Industrial Group has developed a smart tire that measures pressure, temperature and mileage.

At present, tires are passive elements. This means that although they carry out the functions they were designed for, they neither measure contact and working conditions nor do they perform any actions to influence the vehicle's handling. However, as the tire is the point of vehicle-road interface, it is easy to imagine the possible improvements in vehicle handling and tire characteristics that could be achieved with active tires.

The general layout of the Barez smart concept is shown in Figure 1. The Barez smart tire has three main components, as shown in Figure 2: a sensor package, a control unit and a smartphone application.

Information is sent directly to the control unit and then to the driver's cell phone. If the control unit detects a fault in the tire, it sends a warning to the driver via the Barez smart tire application. This app, which is an interface between the sensor package and the control unit, will provide the driver with beneficial information on the tires and any relevant advice.



A display of accurate, color-coded pressure and temperature values enables the driver to see in real time whether the tires are operating within their optimum range.

The Barez smart tire assists the driver before, during and after vehicle use. The application recommends the most suitable pressure for the vehicle. Then, during driving, the sensor gives real-time information on the pressure and temperature of each of the four tires on the vehicle while monitoring these parameters constantly. The mileage of each tire is also captured. Finally, the information is stored and can be accessed after the session. The application then indicates the adjustments to make before getting back on the road.

Many issues had to be considered regarding the installation of sensors in the tire. First, because the stiffness of the tire rubber is very low, conventional foil gauges designed for metal or plastic materials are not suitable. The high stiffness difference may cause the de-bonding of sensors from tire rubber or a reduction in performance of the tire because the sensors themselves inhibit deformation of the carcass. Second, it is impossible to house larger sensors within the interior space of the tire. Additionally, it is not economically viable to use expensive sensors because tires are comparatively inexpensive products.

As the final step in the development of the smart tire, the sensor package must be attached to the innerliner of the tire. It is clear that to support this part, a protective shell is required. Analyses conducted by researchers at the Barez Innovation Center showed that if the material of this shell and the innerliner is the same, the bonding

between them will be reliable.

Considering this issue, the protective shell was compression-molded using a hydraulic press at a temperature of 180°C for 15 minutes. Figure 3 shows a drawing of the manufacture process considered for this part.

To attach the shell to the tire, a comparison between different glues was made based on the bonding strength. It was found that a polyurethane-based glue provided sufficient adhesion of the shell to the innerliner to ensure that these two parts were not separated from each other during dynamic tests of the tire. Figure 4 shows the sensor package and the protective shell attaching to the tire innerliner.

### Conclusion

To satisfy the tire safety requirements, especially for autonomous vehicles, the automotive industry is seeking comprehensive and cost-efficient monitoring systems to better track tire condition. The smart tire is a new type of tire that can check the tire characteristics on its own initiative rather than passively like a conventional tire, and raise an alarm automatically when abnormal conditions are encountered. Also, data is recorded and viewed, compared and shared in the smartphone application. Therefore, the tire characteristics can be monitored and the necessary adjustments to tire parameters, e.g. pressure, can be made in a timely manner. **tire**

### References

- 1) APOLLO Consortium: *Intelligent tyre systems-State of the art and potential technologies*, Technical Research Centre of Finland (VTT), APOLLO Deliverable D7 for Project IST-2001-34372, 2003
- 2) APOLLO Consortium: *Final report including technical implementation plan (annex)*, Technical Research Centre of Finland (VTT), APOLLO Deliverable 22/23 for Project IST-2001-34372, 2005

Figure 3: Drawing of the protective shell

Figure 4: The sensor package and its protective shell attached to the tire innerliner

- 3) European Transport Safety Council *Road accident data in the enlarged European Union* (2006), pp1-30
- 4) Makinen T and Wunderlich H, *Intelligent tyre promoting accident-free traffic*, Proceedings, The IEEE 5<sup>th</sup> International Conference on Intelligent Transportation Systems (2002), IEEE
- 5) Lee H and Taheri S, *Intelligent tires? A review of tire characterization literature*, IEEE Intelligent Transportation Systems Magazine (2017), 9(2): pp114-135
- 6) Wang F et al, *The research of smart tire and correlative core techniques*, Tire Industry Sinica (2002), 22(12): pp713-719
- 7) Zhang X et al., *Intelligent tires based on wireless passive surface acoustic wave sensors*, Proceedings, The 7<sup>th</sup> International IEEE Conference on Intelligent Transportation Systems (IEEE Cat. No. 04TH8749) (2004), IEEE
- 8) Schimetta G et al, *Wireless pressure and temperature measurement using a SAW hybrid sensor*, 2000 IEEE Ultrasonics Symposium, Proceedings, An International Symposium (Cat. No. 00CH37121) (2000), IEEE
- 9) Braghin F et al., *Measurement of contact forces and patch features by means of accelerometers fixed inside the tire to improve future car active control*, Vehicle System Dynamics (2006), 44(sup1): pp3-13
- 10) Moon K S et al, *Tire tread deformation sensor and energy harvester development for smart-tire applications*, Sensors and Smart Structures Technologies for Civil, Mechanical and Aerospace Systems 2007 (2007), International Society for Optics and Photonics
- 11) Pohl A, Steindl R and Reindl L, *The 'intelligent tire' utilizing passive SAW sensors measurement of tire friction*, IEEE transactions on instrumentation and measurement (1999), 48(6): pp1041-1046
- 12) Magori V, Magori V R and Seitz N, *On-line determination of tyre deformation, a novel sensor principle*, 1998 IEEE Ultrasonics Symposium, Proceedings (Cat. No. 98CH36102) (1998), IEEE
- 13) Esmaeeli R et al, *A rainbow piezoelectric energy harvesting system for intelligent tire monitoring applications*, Journal of Energy Resources Technology (2019), 141(6)