Tire Pressure Monitoring

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Proper tire inflation pressure improves fuel economy, reduces braking distance, improves handling, and increases tire life, while underinflation creates overheating and can lead to accidents. Approximately 3/4 of all automobiles operate with at least one underinflated tire [1]. The main causes of underinflation are natural leakage, temperature changes, and road hazards [2]. Drivers typically do not check tire pressure unless they notice unusual vehicle performance. Visual checks are often insufficient to determine underinflation.

In 2000, the U.S. Transportation Recall Enhancement, Accountability, and Documentation Act (TREAD) requested that the National Highway Transport Safety Authority (NHTSA) investigate the implementation of a pressure-drop warning system on vehicles. Beginning with 2006 models, all passenger cars and trucks in the United States are required to have tire-pressure monitoring systems (TPMSs) [3]. A TPMS is a driver-assist system that warns the driver when the tire pressure is below or above the prescribed limits.

TPMSs are classified into two categories, namely, direct and indirect. In direct TPMSs, the pressure drop is calculated based on actual pressure measurements through sensors. In contrast, measurements such as wheel speed are used in indirect TPMSs. A direct TPMS can inform the driver about pressure deviations as low as ±0.1 bar, that is, ±1.45 psi. The following sections explain these types of TPMS in detail.

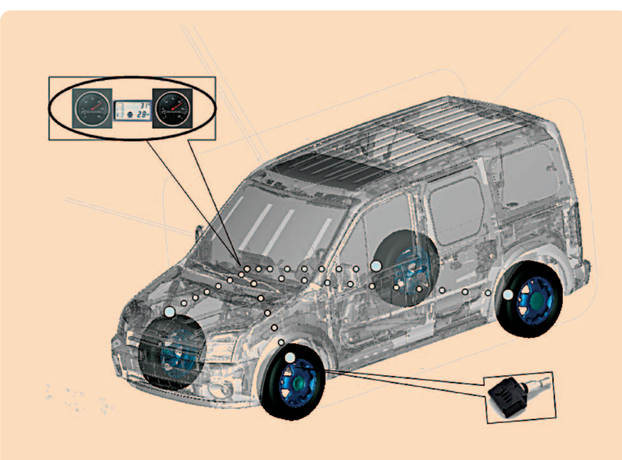

FIGURE 1 A direct tire-pressure monitoring system. Sensors in each tire measure pressure. The data are transmitted to a receiver located on the dashboard, which indicates loss of pressure.

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DIRECT TPMS

Tire inflation is identified through pressure sensors in a direct TPMS. A low-cost, simple direct TPMS consists of a sensor fitted on the tire valve stem, which changes its color when the pressure drops. This sensor has low accuracy and cannot communicate data to the driver. Alternatively, a more sophisticated version of a direct TPMS consists of sensors, radio frequency transmitters and receiver, and a warning system as shown in Figure 1. Each tire's pressure is measured and transmitted through its sensor and transmitter. The transmitted signals are received, decoded, and processed by the receiver to trigger the warning system through an alarm lamp, audible alarm, voice, or pressure display.

Sensor Module

The sensor module must be small in both size and weight to minimize the effect of centrifugal forces. The module is designed to operate between −40 °C and 120 °C. For example, a tire pressure sensor manufactured by Hella, Inc., shown in Figure 2(a), consists of a sensor, transmitter, antenna, and control unit as well as a long-life battery to supply energy. This pack has a valve stem, which is inserted from inside the tire through a hole on the wheel rim as shown in Figure 2(b). The aluminium cap of the valve stem acts as an antenna, while the nickel valve core helps prevent corrosion.

Most TPMS sensors feature a pressure transducer manufactured with CMOS technology, which provides low energy consumption. The sensor is designed together with an analog-to-digital converter and nonvolatile memory to store tire pressure data. In advanced models, a temperature sensor is also embedded with the pressure sensor. To control the functions of the sensor and transmitter, a microcontroller is fitted on the sensor module. A software routine is loaded in the flash memory of the microcontroller to define its operation.

Optimal utilization of battery energy is crucial since it cannot be replaced easily. The radio frequency transmission stage expends five times more energy than the sensing stage. Various energy-management techniques are used to save battery energy. In some models, when the

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vehicle is parked, the sensor transmits the signals once an hour, while other models are equipped with speed detectors that shut down the transmission. More sophisticated sensor modules contain a low-frequency receiver integrated circuit, which waits in standby mode and wakes up the sensor once it detects a trigger from the vehicle's main processor. This technique is called pressure on demand. In the sensor module circuit shown in Figure 3, each sensor is coded differently so that the receiver can distinguish between tires. If one of the tires is replaced or if the tires are interchanged, the sensor or sensors must be reset.

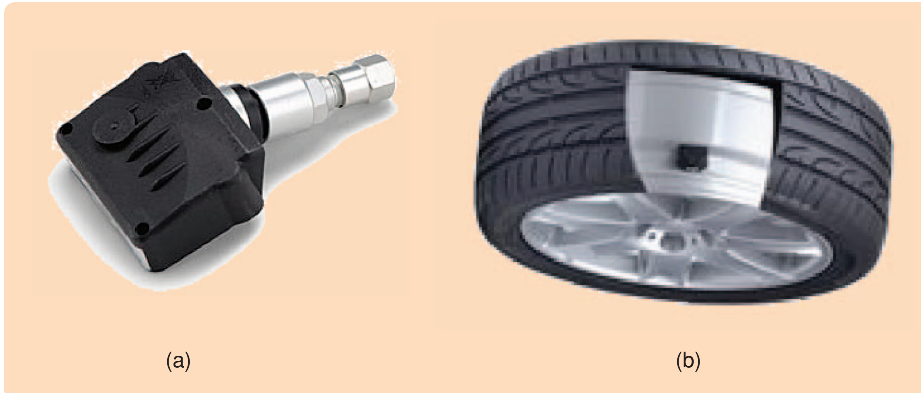

FIGURE 2 (a) Sensor module and (b) its fitting. The mass of the sensor is minimized to reduce the effect of centrifugal force due to rotation of the tire. The pressure sensor is mounted on the tire rim. The valve stem acts as an antenna for the built-in transmitter. (Printed with the permission of Hella, Inc.)

Receiver Module

A receiver module consists of an antenna and control unit in which data are received and transferred to a central processor to trigger the warning system. In advanced models, the receiver module is portable with a built-in processor, display unit, and warning system, which can be placed within the driver's reach. This unit is powered by either its own battery or the car battery. The receiver is programmed by the manufacturer to associate each sensor with a corresponding tire and needs to be reprogrammed when a tire or sensor is replaced. The receiver can be integrated with the vehicle remote keyless entry system through proper design of the transmission frequency and protocols. The basic portable receiver display unit has color symbols with an LED specific to each tire to identify the underinflated tire as shown in Figure 4(a), while advanced models can display icons and tire pressure as shown in Figure 4(b). A challenging task of the receiver is to avoid data interference from nearby vehicles.

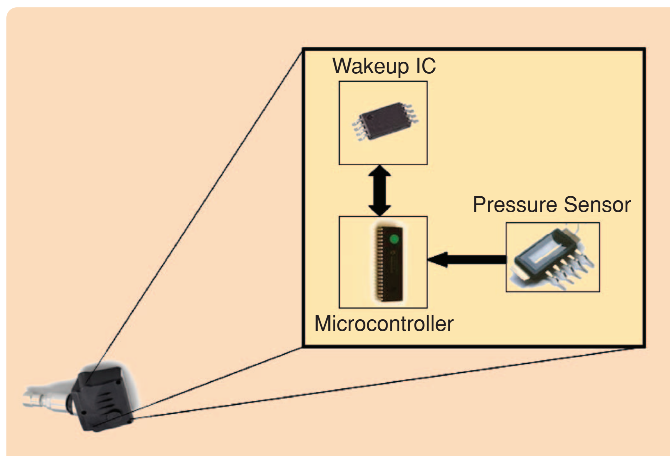

FIGURE 3 Pressure-on-demand sensor module circuitry. This module includes a transmitter, wakeup unit, microcontroller, and sensor. As long as the vehicle is stationary, the tire pressure sensor stays in sleep mode.

INDIRECT TPMS

An indirect TPMS predicts tire pressure drop using an observer coded in software and thus does not require tire pressure sensors. Available indirect TPMSs are based on wheel-speed measurements. When the tire pressure decreases, the vehicle's weight causes the tire's diameter to decrease, which causes the tire to rotate at a different rate than when it is at full pressure. In particular, the tire angular speed ω is given by

$$\omega = \frac{v}{r - \delta_r}, \quad \delta_r = r - r_c,$$

where v is the vehicle's speed, r is the tire's nominal radius, r_c is the tire's effective radius, and δ_r is the tire

FIGURE 4 Receiver with display. Display technology ranges from (a) portable units with LEDs to indicate tire pressure loss to (b) advanced built-in units that display tire pressure. (Printed with the permission of SmarTire, Inc.)

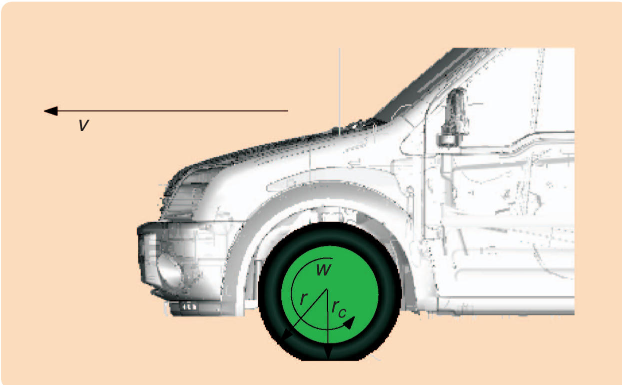

FIGURE 5 Tire and vehicle speeds. Tire pressure changes result in changes in tire rotational speed. Tire rotational speeds are measured in all vehicles by the antilock braking system.

deflection as shown in Figure 5. Automobiles with an antilock braking system provide the rotational speed ω of each tire to the central processor. A simple algorithm based on monitoring of the inflation measure β defined by

$$\beta = \left|\frac{(\omega_{\mathrm{LF}} + \omega_{\mathrm{RR}}) - (\omega_{\mathrm{RF}} + \omega_{\mathrm{LR}})}{\omega_a}\right|,$$
$$\omega_a = \frac{\omega_{\mathrm{LF}} + \omega_{\mathrm{RR}} + \omega_{\mathrm{RF}} + \omega_{LR}}{4}$$

is used to predict tire underinflation, where ω_{LF}, ω_{RF}, ω_{LR}, ω_{RR} denote left front, right front, left rear, and right rear wheel angular velocities, and ω_a is the average angular speed. The tire inflation measure β is close to zero for normal tire pressure. Therefore, only software is needed to implement an indirect TPMS. However, several shortcomings are associated with indirect TPMS. First, the system does not provide the actual pressure of each tire and works only when the vehicle is in motion. Additionally, the system does not give a warning when two tires are equally underinflated on the same side or same axle or when all four tire pressures are equally low. It warns the driver only when the pressure drop is more than 25% and, moreover, may generate false warnings when the vehicle is moving on a curved road or during tire slip on snowy roads.

HYBRID TPMS

A hybrid TPMS, which integrates a direct TPMS with an indirect TPMS, is designed to overcome the shortcomings of indirect TPMSs. A hybrid TPMS consists of two pressure sensors fitted on diagonally located tires in conjunction with an indirect TPMS algorithm as shown in Figure 6. When two tires are on the same side, on the same axle, or all four tires are equally underinflated, the indirect TPMS cannot predict the underinflation. These situations can be identified by using the two direct pressure measurements.

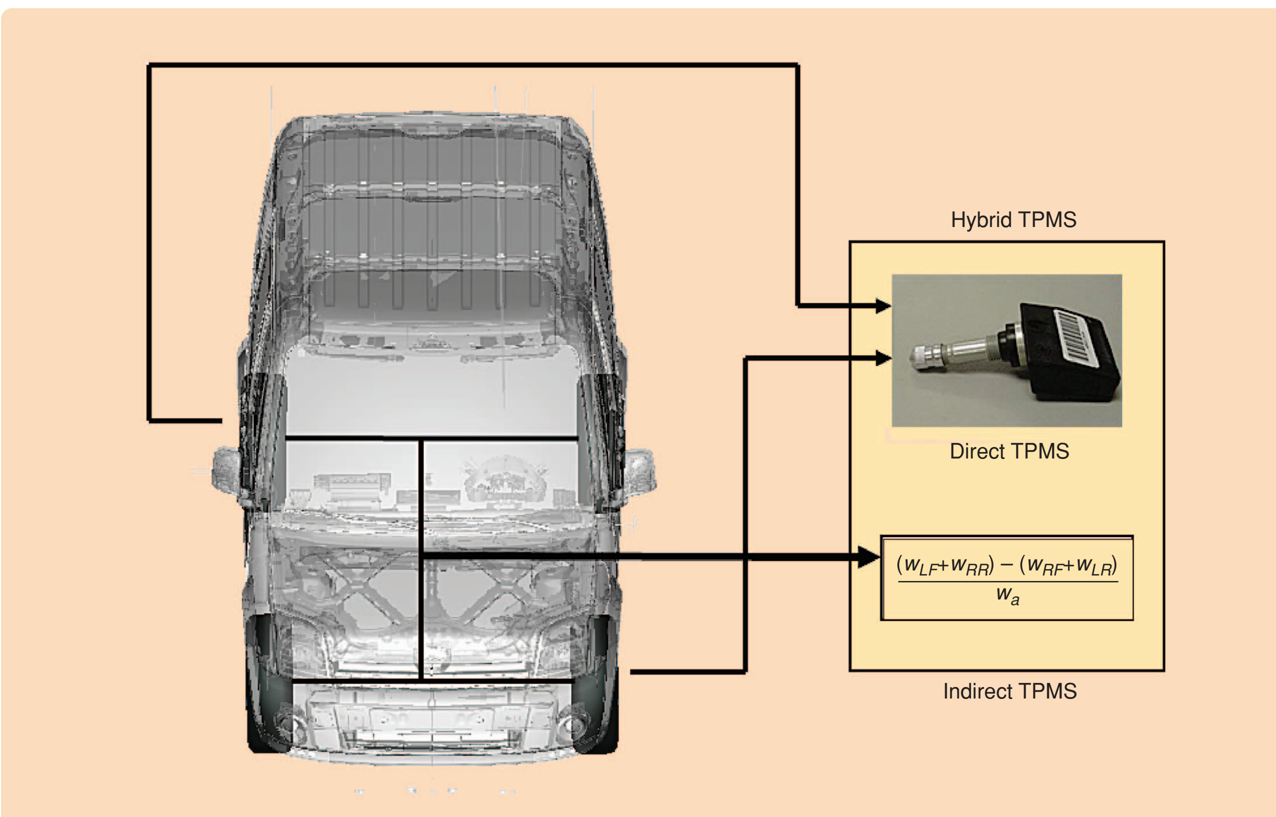

FIGURE 6 Hybrid tire pressure monitoring system configuration. A hybrid TPMS, which is a combination of a direct TPMS and an indirect TPMS, uses fewer tire pressure sensor modules than a direct TPMS.

FUTURE DIRECTIONS

Tire modeling and tire parameter estimation are needed to reduce the cost of direct TPMSs and to overcome the shortcomings of indirect TPMSs. A classical solution is to model the dependence of tire/road friction on tire pressure, which can then be extracted from the friction coefficient. Alternatively, one can consider additional factors that affect tire inflation pressure, such as vertical force and vertical deflection [4]. A combination of tire speed and tire height can estimate inflation more precisely than current indirect TPMSs. This approach needs an additional height sensor or accelerometer, which is available in vehicles with semi-active or active suspensions.

Yet another approach relies on the fact that the resonance frequency of the tire changes with respect to pressure [5], [6], as modeled by

$$\omega_{\text{resonance}} \cong \sqrt{\frac{k - \Delta_k}{m}},$$

where k denotes tire stiffness, Δ_k denotes change in tire stiffness, and m denotes mass acting on the tire. If the tire pressure changes, then the spring constant changes, resulting in a change in the natural frequency. The wheel vibration can be measured either by the tire speed or through an accelerometer. Alternatively, tire inflation can be identified through nonlinear identification techniques, which rely on tire stiffness changes with respect to pressure [7].

Due to the U.S. law mandating direct TPMSs, sensor industries are interested in producing cost-effective solutions. While promising theoretical and practical results [4]–[7] are available for indirect TPMSs, they have not yet appeared in commercial products.

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Power Kites for Wind Energy Generation

Fast Predictive Control of Tethered Airfoils

BY MASSIMO CANALE, LORENZO FAGIANO, and MARIO MILANESE

The problems posed by electric energy generation from fossil sources include high costs due to large demand and limited resources, pollution and CO_2 production, and the geopolitics of producer countries. These problems can be overcome by alternative sources that are renewable, cheap, easily available, and sustainable. However, current renewable technologies have limitations. Indeed, even the most optimistic forecast on the diffusion of wind, photovoltaic, and biomass sources estimates no more than a 20% contribution to total energy production within the next 15–20 years.

Excluding hydropower plants, wind turbines are currently the largest source of renewable energy [1]. Unfortunately, wind turbines require heavy towers, foundations, and huge blades, which impact the environment in terms of land usage and noise generated by blade rotation, and require massive investments with long-term amortization. Consequently, electric energy production costs are not yet competitive with thermal generators, despite recent increases in oil and gas prices.

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