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THE IMPORTANCE OF ACTIVE AND INTELLIGENT TIRES FOR AUTONOMOUS VEHICLES

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16. Abstract

Because of their unique functions and place on a vehicle, tires have the potential to become a more integral part of active and intelligent autonomous vehicles than has been the case for human-controlled conventional vehicles over the past century. This brief white paper touches upon several needs that future tires may be able to address, or at least, assist with. The tire solutions to the various needs fall into two main tire categories:

• *Active tires* (tires that are able to "do something" dynamically in response to environmental or vehicular conditions or changes in the state of the tire itself), and

• *Intelligent tires* (tires that are instrumented and able to "sense something" about the state of the tire itself or the immediate environment where the vehicle is operating, and communicate this information to the higher-level system operating the vehicle to optimize its performance).

The nature of the discussion in this paper is forward-looking, and some of the concepts are still in the developmental stages. Therefore, while some of the discussed concepts will prove to be the most ideal or cost effective solutions to the needs of an autonomous vehicle, others will not.

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Introduction

As part of their recent guidance for the development and introduction of autonomous vehicles, the U.S. Department of Transportation expects driving as we have known it since the introduction of the automobile over a century ago to change significantly with the introduction of such vehicles (U.S. DOT, 2013). However, one facet that will remain unchanged for any foreseeable future is the fact that tires will continue to be the only part of a vehicle in direct contact with the roadway. All of the forces essential for controlling a vehicle (steering, accelerating, braking) ultimately rely upon the tires to exert such forces. Additionally, a vehicle's tires play an important role in providing a smooth, comfortable ride for the passengers. As such, tires are uniquely positioned (both figuratively and literally) to provide critical information about the state of the vehicle, the roadway, and the tire itself. Furthermore, without an actual human "driver" in the traditional sense, the ability to monitor the amount of wear and overall condition of the tires from day to day must be shifted to the vehicle itself. In many situations, it may be helpful for the vehicle to 'know' what types of tires it has been equipped with and whether or not they are appropriate for the conditions.

Winter tires provide a good example of this need for the vehicle to know about its current equipment. Winter tires are required on certain roads or when severe winter conditions are present in several countries and some states within the U.S. (e.g., California DOT, 2016; Colorado DOT, 2016; European Commission, 2016); still other governments require winter tires on all roads throughout the winter months (European Commission, 2016; Gouvernement du Québec, 2016). Furthermore, the performance of vehicles in winter driving is significantly different with or without winter tires (Woodrooffe, 2016), and an autonomous vehicle will need to take this into account when performing most vehicle maneuvers (such as steering, accelerating, and braking). This need for a vehicle to know what type of tires it is equipped with is just one example of the various useful, or even critical, pieces of information tires may need to provide to future driverless vehicles. (It is assumed in the above examples that an autonomous vehicle would be capable of knowing its precise physical location and the corresponding traffic laws for that jurisdiction, including common variations or nuances like winter tire requirements.)

This brief white paper explores the various functions and related benefits that might be possible with future, advanced tire designs. The importance of each advanced function to an autonomous vehicle (AV) system's awareness of the vehicle's physical state or condition will also be briefly discussed.

The nature of the information in this white paper is forward-looking, focused on advanced and/or future tire features or designs that may assist in (or be necessary to) the introduction and effective use of AVs. While the focus here is on possible advancements and contributions of tires to AV design and usage, it may be the case that certain advanced tire concepts are not necessarily the most ideal or cost effective solutions to the problems identified in this paper. The advanced functions and designs discussed in the paper are based, in part, on publicly available information regarding the current state of research and development with the major tire manufacturers, but are not a complete list or accounting of the technological developments underway to further advance current tire designs, features, and applications. Additional background information for this report was obtained through personal, interactive discussions with representatives from several major tire manufacturers. Given the highly prototypical nature of the technologies described here, we do not attempt to evaluate the general feasibility of each technology in the long term. Instead, this paper discusses and summarizes specific anticipated data needs for AVs (including roadway data as well as self-diagnostic vehicle and tire data) and the corresponding developments within the tire industry that may ultimately align with such needs.

Future advanced tires—whether for the benefit of AVs, or for more traditional vehicles driven by human drivers—can generally be classified into two broad categories: active tires, and smart/intelligent tires. The following sections will discuss the various advantages and potential contributions of each tire category.

Active tires

As the name implies, active tires are tires that are able to "do something" in response to environmental or vehicular conditions or changes in the state of the tire itself. Tires (or the AV system itself) capable of dynamically responding to changing conditions will increase in importance as we reach the point when AVs will frequently be operated empty or by individuals who may be incapable of monitoring and/or responding to issues that arise with the vehicle's tires (such as the very old, young, disabled, or individuals with limited physical mobility). The following subsections discuss some of the more prominent areas of active tire development and corresponding needs when operating a highly advanced or intelligent AV system. Such systems should ultimately be capable of responding to input about changes to the condition of the vehicle, either by remedying the problem, notifying the vehicle owner of the problem, and/or modifying the underlying vehicle performance parameters.

Inflation and tire pressure

A key factor in safe and predictable vehicle performance is proper tire pressure. Current tire pressure monitoring systems (TPMS) are required by law (NHTSA, 2002) and already perform such tasks to some extent. To avoid unsafe AV operation resulting from vehicle performance parameters being misaligned with the current state of the tires (as well as many other parts of the vehicle), it will be important to integrate TPMS sensor data and the specific tire positions with an AV system's overall awareness of the vehicle's condition. Of added benefit would be features or technologies that allow for AVs to change their own tire pressure(s) automatically (whether deflation or inflation is required). Some conditions, such as deep (yet drivable) snow and sand, may require higher or lower tire pressures for optimal performance. Conversely, a tire that has slowly lost pressure over time and normal usage would benefit from technology that allows for automatic re-inflation (i.e. self-inflation) without the need for human intervention (assuming a tire puncture or other rapid leak is not present). While some existing systems have employed traditional air compressors to accomplish the task of re-inflation, more recent advanced tire designs suggest that the physics and motion of the tire itself can be used to add pressure to a tire that is otherwise low (but not to inflate a damaged tire or one with complete loss of pressure).

It is possible to avoid the complexities of managing tire inflation and pressures altogether by employing an airless (i.e., non-pneumatic) tire and wheel combination. Such assemblies generally consist of a tire tread and wheel assembly supported by flexible spokes within the wheel, rather than a flexible air cushion provided by a traditional tire mounted on a rigid wheel. Airless tires are already in use for non-AV off-highway applications (construction, demolition, and military), especially when there is a high risk of tire punctures.

Weather-sensitive tires

In combination with the inflation and tire-pressure features described above, tires that are capable of adapting to changes in weather conditions can help to maintain the standard performance and handling characteristics programmed into AVs. While the need to adapt the driving characteristics of an AV in response to changes in weather conditions is unavoidable, tires that could adapt to offer improved performance relative to traditional tires would allow for more uniform driving performance under less-than-ideal weather conditions. For example, work has been done to examine the capabilities of advanced features in tread compounds that can allow for stiffer tread material and better handling when dry, yet can absorb moisture when wet to become more pliable, thereby improving wet handling. Additionally, materials capable of responding to changes in warm versus cold roadways could improve the range of handling similar to changing from summer to all-season to winter tread compounds. Studies have shown that winter tires outperform non-winter tires when road surface temperatures are below 7 °C (45 °F), even when ice and snow are not present (Woodrooffe, 2016).

Tires with variable treads (touring, all-season, winter, etc.) or wear areas

To enable AVs to select and use the best tread based on changes in the roadway surface type, surface condition, or overall weather conditions, tires with the ability to apply variable (selectable) treads would greatly enhance the range of environments where an AV could safely operate. Selectable treads would also enable AVs to make such changes to the vehicle's equipment as needed, without human intervention (Phys.org, 2012). The same technology could also allow for variable wear areas on each tire, extending the tire's life (i.e., the time with safe, usable tread depth) by effectively varying the tire's 'contact patch' area that touches the roadway. Examples of the ability to vary tire treads and/or wear areas include spherical tires[†] and tires with variable inflation bladders (corresponding to each unique tread pattern or desired contact area on the tire).

Intelligent (or smart) tires

Intelligent or smart tires are instrumented tires that are able to "sense something" about the state of the tire itself, or about the immediate environment where the vehicle is operating (i.e., the roadway), and communicate that data back to the higher-level AV system operating and monitoring the vehicle to optimize the performance of the vehicle.

Sensing the state of the tire

As mentioned in the previous section regarding existing TPMS sensor data, integration of such tire-related information with an AV system's overall awareness of the vehicle's condition is critical to avoid unsafe or suboptimal AV operation resulting from vehicle performance parameters being misaligned with the current state of the tires. In addition to the importance of monitoring factors such as tire pressure from moment to moment, other important tire-specific information may also be captured and communicated by tire-mounted sensors. As with the real-time monitoring of pressure, the safe and optimal operation of an AV in the long-term (or in specific scenarios or environments) will benefit from the ability of an AV system to maintain awareness of the overall current state (i.e., both the nominal specifications and the instantaneous health) of the tires. Examples of information important to monitoring the current state of a vehicle's tires include:

- Pressure
- Tread depth
- Tread temperature
- Contact patch area/size
- Tire load
- Rotation history
- Tire age, mileage, and overall health

[†] It should be noted that such advanced tire designs (and corresponding wheel designs) would also require a major redesign of the vehicle-tire interface to actually allow for effective operation of the vehicle as described.

- Performance changes such as stiffness, etc.
- Tire type (all-season, winter, etc.), unique identification, and specifications (data embedded when manufactured, such as on RFID[‡])
- Manufacturing date and related information (may also be embedded on RFID or similar device)

In addition to monitoring and maintaining a situational awareness of the various conditions and overall state of the tires, the most intelligent AV systems would also be expected to respond to the changing nature of such data (from a combined active and intelligent tire), either by adjusting the underlying performance parameters of the vehicle based on degraded tire conditions, and/or recommending required maintenance schedules to the vehicle owner to ensure continued safe vehicle performance.

Sensing the state of the roadway

As the sole piece of equipment on any vehicle—from passenger vehicles up to the heaviest tractor-trailers—that is in contact with the roadway, tires can potentially assist in providing additional information about the immediate environment that may otherwise be difficult or impossible to obtain. Examples of roadway information that might be supplied by tire-mounted sensors include:

- Roadway type or material
- Roadway temperature
- Roadway wetness (dry, wet, snow, ice)
- Friction with the roadway

As discussed above regarding sensing the state of the tire, an intelligent AV system ideally would respond to the changing nature of such data, adjusting the underlying performance parameters of the vehicle based on the specific roadway conditions directly under that vehicle at any given time, thereby ensuring safe performance through real-time measurement of the roadway.

[‡] Radio-frequency identification (RFID) technology is already in use for specialized tire applications, such as tracking approved tires used in Formula One, NASCAR, and similar classes of auto-racing (Automotive IT News, 2015).

Conclusion

This white paper briefly touched upon several needs that future tires may be able to address, or at least, assist with. While it is possible that some of the concepts discussed will prove not to be the most ideal or cost effective solutions, others likely will. Because of their unique functions and place on a vehicle, tires have the potential to become a more integral part of active and intelligent autonomous vehicles than has been the case for human-controlled conventional vehicles over the past century.

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