Autonomous Tread Identification System

Senior Design I Student Proposal
University of North Texas Department of Electrical Engineering
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I. Problem Definition

Tire-related issues, including blowouts, tread separation, and worn tread, are some of the most common causes of vehicle accidents. In 2015, more than 35,000 people died from motor vehicle accidents in the United States alone. For every person killed in a motor vehicle accident, 8 people were hospitalized and 99 people were treated and released from emergency departments [1]. The NHTSA has reported that on tire-related crash vehicles, 26.2% of tires had a tread-depth of the legal minimum of 2/32" or less [2, pp. 8-9]. We propose a low-cost, easy to install autonomous tire tread sensor to alert vehicle operators to uneven or dangerous tread on their tires.

A. Background

A tire is made up mostly of rubber and has built-in innovative securities to allow the rubber to have traction on road surfaces. The main addition to the rubber on a tire is called tread. The tread of the tire is what contacts the driving surface and has been engineered to grab or grip the surface it impacts and travels on. It is developed by creating unique designs on the surface on the circumference of the tire. The tread is designed with tread blocks, ribs, grooves, and sipes.

Tread blocks are the raised part of the tread that contacts the surface of the roads. The rib is a solid, but narrow, strip around the center of the tire. The grooves are the canals and larger gaps that separate the tread blocks, creating an innovative path for water and air to flow. This allows for more grip and better traction. Sipes are small grooves in the tread that allow for more accurate traction control and, in some cases, more comfort and less vibrations as the tires rotate on the surface of the roads.

B. Current Products

Currently, some companies are working on devices that detect low tread on tires. Continental, a large tire distribution company, has proposed tread monitoring sensors embedded on the inside of tires. While they patented their RFID based solution in 2007 [3], the sensors have still not been released for passenger vehicles. Another company, Tyrata, has received nearly $4.5 million in funding to develop their proprietary sensor, IntelliTread [4]. This product is also embedded inside the tire to detect tread wear. IntelliTread is made from materials such as carbon nanotubes, making it prohibitively expensive to develop. In addition, this product has also not yet been pushed to the market. Many other devices have been patented in recent years that use systems embedded in the tread or the tire itself (see [5]–[8]).

C. Proposed Product

We propose an Autonomous Tread Identification System (ATIS) using either a wear-down sensor or a Light Detection and Ranging (LIDAR) sensor to reduce the risk of injuries and deaths related to vehicle accidents. To be effective, the tread identification system must accomplish the following

- Continuously provide reliable measurements/readings for each tires tread depth at a low-cost
- Display the measurements/readings in an understandable form and safe manner to the driver
- Ensure the sensors are easily replaceable for a possible faulty device or buying new tires

Unlike the current researched products, the ATIS will be nearly ready for the market by the end of this project. The product will be easily installable on most passenger vehicles, so that new tires do not need to be purchased to see the benefits of the sensor. The ATIS will be a low-cost device so everyday consumers can afford it. This will also allow commercial vehicles, such as semi trucks, to implement the device on a fleet-wide scale for large cost savings.

The tread detecting system can also lead to improved tire maintenance. The system operates by informing drivers on when to go to a mechanic shop, which will lead to expenditure saving opportunities for customers. The system will keep the customer more informed on when they may need to purchase tires rather than feeling like they were manipulated or tricked into buying tires due to a lack of knowledge. The customer will become more trusting of sales representatives because a system is also informing them of needing new tires, which will inevitably create a better bond between customer and expert.

Once the ultimate goals of ATIS has been achieved, we could further increase the specifications of the system by dynamically estimating a tires lifespan based on the drivers habits and detecting foreign metal objects penetrating the tire. If successful, we could release the product to surrounding semi truck, automobile services, and tire manufacturer companies at a low-cost and profitable rate.

Terminology:

- NHTSA - National Highway Traffic Safety Administration
- ATIS - Autonomous Tread Identification System
- LIDAR - Light Detection and Ranging
- Tread - A special type of rubber surface along the circumference of a tire that enables a tire to grip the road to provide traction and stability when maneuvering a vehicle.
- Tread Depth - The depth of the grooves in the tread. A minimum value of 2/32” is the legal minimum requirement and most new passenger vehicle tires are produced at 12/32”.

II. Researching and Generating Ideas

Aside from ATIS, our team generated and researched many other product ideas. One of the most promising ideas is a Robotic Automated Delivery (RAD) system. This system is an autonomous robot that delivers packages and mail. There were two possible implementations of the system. First, the robot is designed to collect packages from a centralized mail room. For each package, it would identify the room location and autonomously deliver the package to the appropriate location.

Second, a fleet of robots could be deployed from a package delivery vehicle. Each robot could be given packages for a few houses and the vehicle could release the fleet every few blocks. This would allow packages to be delivered rapidly with a distributed system. Both products could potentially save significant manpower and payroll costs.

For both implementations, the main difficulty is in mapping an area and autonomously choosing an optimal path. Additionally, motorized delivery robots can easily be replaced by delivery drones. These drones are already being designed and implemented by Google, Amazon, and other large companies.

A second potential idea we developed is a smart pool sensor. The smart pool sensors currently on the market are generally fairly unreliable and do not automatically correct for chemical imbalances in a pool. Our improvement over this is to develop a system that accurately measures chemicals in a pool. A consumer could then connect to the device through a bluetooth connection on their mobile device to view current chemical measurements.

The system would also be connected to a system to automatically release and disperse chemicals into the pool when the chemicals in the pool are imbalanced. The consumer would also receive notifications when within range of the system if the level of chemicals in the dispersal system need to be replenished. A further improvement over traditional chemical sensors is the ability to measure close to twelve inches below the surface of the water. This allows for a much more accurate reading of the pools chemical balance. The pool sensor project was discarded as the main improvement could be simplified to simply more accurate measurements as well as the simplicity of chemical disbursement.

The final potential idea we considered is a vacuum drone to clean dirt off of hard to access areas such as rafters and high window sills. Initial stages of the drone would be user-operated to test the flight time and to focus on a lightweight design. Afterwards, the drone would be made autonomous to automatically detect surfaces to vacuum off of the floor. Such devices would be extremely useful in large buildings where it is not feasible to move ladders around to reach high, flat surfaces to clean dust and trash off of. It would also be useful in homes with windows that are high off the ground and chandeliers. The main difficulty of this problem is that the building of the drone by itself would take the majority of the allotted time. Due to time constraints, few improvements could feasibly be implemented.

III. Conception, Requirements, and Specifications

Due to one of our members work history in the automotive industry, we initially looked towards vehicle technology. We considered the many significant safety issues drivers currently face when operating their vehicles. We also considered the safety and maintenance issues of fleet and commercial vehicles such as semi trucks. This led us to the conclusion that the most effective safety system for a vehicle would be a sensor to assist with preventive maintenance. When considering the effect a tires condition can have on a vehicle, including stability, traction, and fuel economy, we decided that a sensor that can detect tread wear could potentially lead to the highest cost savings and prevent the most serious accidents.

A. Conception

While tire pressure monitoring systems are already a standard in all newer vehicles, tire tread is generally not checked unless a vehicle is routinely taken in for a tire rotation, alignment, or an air pressure check. These check-ups generally only occur every 5,000 or more miles, which may mean that the tread on some tires is only checked once a year. Because of this, a tire tread sensor is necessary to ensure continued safe operation of a vehicle. Such a sensor would be able to accurately detect any uneven tread wear or dangerously low tread on a tire assembly. The sensor will then alert the driver that maintenance is required to correct the tire tread issues. With further improvements, the device may also be able to detect impurities in the tire or objects lodged in the tire, which could result in a blown tire.

ATIS will be a valuable technological advancement to the automotive industry by improving the safety and enhancing the knowledge of the driver related to the vehicle. Companies in the automotive industry can use this new tool to explain to their customers how to ensure a safe driving experience. Companies will also be able to have a visible monitor that teaches their customers safety. This will instill a more trusting relationship between salesman and customer by giving the customer something more tangible to work with.

In addition, companies with fleet vehicles will be able to monitor the tread wear of their vehicles more easily; thus allowing for more efficient tire changes while simultaneously reducing the risk to both their own drivers and drivers in the vicinity of their vehicles. This will allow for more efficient maintenance, resulting in more productivity for the company.

B. Requirements

The tread sensor must be able to measure tire tread depth at a resolution of a minimum of 1/64". The sensor must also be able to be either attached to the inside of the wheel well or embedded on the inside of the tire. This requirement will be further specified in further revisions as either the LIDAR or wear sensor is selected to measure tread depth.

In order to ensure durability of the device, it must be able to withstand the general distress of normal highway and surface road driving. This requirement ensures that the device does not need to be frequently replaced and can remain in position for extended lengths of time without needing maintenance or cleaning. Additionally, the device must be extremely low-power to ensure that a battery does not need to be replaced or recharged frequently.

The sensor must wirelessly connect to an in-vehicle notification system in order to alert the driver when the tread depth goes out of a specified range. This notification will allow operators to know the tires need to be replaced soon. This early warning system can prevent the majority of tire-caused accidents.

C. Specifications

In order to meet the given requirements, the product must meet some minimum specifications. To ensure accurate tread wear readings, the sensor will be either a LIDAR mounted on the wheel well, or a wear sensor mounted inside the tire itself. To meet the durability requirements, the sensor will be securely mounted and will be made out of a durable plastic casing ensuring that the sensor and communication technology within is well protected from shock impacts.

To reduce the power consumption of the device, it will not measure tread depth and send any data within a short time after the vehicle has stopped all movement. Further battery optimizations will also be implemented as the design of the product is further created.

IV. Constraints

The main design constraint for this product is budgetary. For the development of this product, we have a small budget and must therefore keep the overall cost of materials and parts to a minimum to stay within the budget. To meet this constraint, the product will be developed out of common parts that are fairly inexpensive. This constraint will assist in keeping the production cost of the final product down, allowing us to meet the low-cost requirement to allow the device to be widely used and affordable by consumers.

Another constraint is the varying size and shapes of tires, as well as different tread designs. Our product will need to be able to accurately assess the state of the tread regardless of tire or tread type. To meet this constraint, thorough testing will have to be done to account for different tire and tread types. Meeting this constraint will give our product a broader consumer base.

The device must also be able to survive any type of weather. Since people drive in all sorts of different weather conditions, we will have to account for how those conditions could affect sensor readings to make sure accuracy is maintained. We also want to prevent damage to the sensor that weather conditions and collisions could cause. These constraints influence the location of the sensor and the materials it is made out of.

V. Ethical, Professional, and Contemporary Issues

The main ethical issue with ATIS is to avoid any harm to human life in application of the system. As ATIS is proposed as an autonomous system, the driver would heavily rely on the system. If the sensor produces inaccurate readings and the driver becomes reliant on the sensor, the tire could become severely worn leading to accidents, injuries, and potential death.

The location of the sensor could result in ethical violations. Without following proper placement of the sensor, the possibility of direct interference between the sensor and assembly could occur over time. The last ethical issue would be the location of the notification display. The ATIS caution light will most likely be displayed next to the TPMS light, which is a part of the MIL lights. The MIL lights are the warning lights that come on when you turn the vehicle on to auxillary mode and or start the engine. An added bonus to this warning ATIS MIL light would be an option for the driver to navigate to a menu that displays the tread depth readings.

VI. Engineering Standards

Because the product communicates wirelessly with a control module, it must comply with all applicable wireless communication standards. Potential standards for this communication include IEEEs 802.15.4, 1451.5-2007, and 802.11 standards. IEEE 802.15.14 defines the operation of low-rate wireless sensors [9]. This standard limits sensors to a 10-meter communication range and a 250 Kbps transfer rate. IEEE 1451.5-2007 defines wireless communications protocols using the existing protocols ZigBee, 802.11, Bluetooth, and 6LoWPAN [10].

VII. Design

The design flow for the product will include a sensor that wirelessly detects tread wear on a tire and wirelessly connects to a central controller. This controller takes the data from the sensor and parses it into a tread depth measurement. If the tread depth is outside of an acceptable range, the operator of the vehicle is notified of the danger. This notification will be inside of the cabin of the vehicle so that the operator can see the notification while driving and does not need to manually check the tires individually to find out if there is an issue.

Currently, we are pursuing two potential designs for the tread sensor. The first option is a LIDAR sensor attached on the inside of the wheel well. This sensor will use light waves to map the surface of the tire as it rotates. Using computer vision algorithms, the tread depth measurement will be calculated and transmitted to the controller to notify the user if necessary.

The second option is to use an embedded wear-down sensor within the tire. This sensor will measure the thickness of the rubber on the tire itself. Once the rubber is less than a certain length, the sensor will notify the controller to inform the user of the danger. While both options are potentially feasible, further research is required to determine which is the most effective low-cost option.

The product itself will be low-cost to allow consumers to afford the sensor. Since many vehicle operators are not car savvy, the system will be designed to be relatively easy to install and set up. In order to prevent frequent replacements, the product will be encased in a protective layer to ensure that it is durable and can last through rough driving conditions and survive impact forces. The on-board battery will be replaceable or rechargable so that the consumer does not need to purchase a new device or replace it. To reduce the frequency of this, the product will be extremely low-power such that replacing batteries or recharging is needed very infrequently.

The final product for this project will consist of a tire tread sensor using either a LIDAR sensor connected to the wheel of the vehicle or a wear-down sensor embedded inside of a vehicle's tire. These sensors will measure the tread depth of the tire and will send this data to the main controller. This controller will then decide if it is necessary to inform the user of any potential danger. This signal to the operator will inform them if it is time, or soon will be, to replace the tire or tires.

VIII. Parts List

Since the design has not yet been finalized, the parts list is not complete. Table I and Table II show the current expected parts required for the two potential sensing options. One will be removed once we decide which sensing option we will further pursue. Currently for each option, a communications module is required to transmit data from the sensor to the main controller. Since the

TABLE I: Parts required for ATIS using a LIDAR sensor.

Part	Quantity
LIDAR Sensor	1
Red LED	1
Microcontroller	1

TABLE II: Parts required for ATIS using a wear-down sensor.

Part	Quantity
Wear-Down Sensor	1
Red LED	1
Microcontroller	1

notification system has not been defined yet, a simple LED is required to notify about dangerous tread depth.

IX. Prototype and System Integration

By the end of this semester, our expectation is to have a working prototype of a sensor to map the surface of a tire using either a LIDAR sensor or a wear-down sensor. The sensor will send the data to a controller that will then determine the approximate tread depth. The controller will then be able to send a notification signal (likely through an LED for prototyping) to alert a customer if the tread depth is outside of a specified range.

Once these functionalities are implemented, the sensor will be improved to measure with a higher accuracy. Then, functional tests on a real vehicle will be conducted with a moving tire. From this point, optimization and further testing will be conducted to improve the device. The housing of the sensor will also be improved so that inclement weather, rough terrain, and dirt do not degrade the measurements taken. Through this process, the sensor will be made with off-the-shelf parts to stay within budget and produce a low-cost final product.

X. Deliverables

Once the product itself is complete, we will compose a final report discussing our findings, results, and conclusions. This report will discuss the specifics of the final product, the difficulties in completing it, and the specific details of how it functions. A poster and presentation will also be prepared to give a high-level understanding of the product and how it functions to business leaders, professors, and peers.

XI. Timeline

To ensure the timely completion of the project, three Gantt charts have been created. These charts supply us with expected milestones for the project. This allows us to visually determine whether or not we are on schedule to complete the project. The Gantt chart is a constantly adjusting figure that will become more specific as the design for the product is further refined. Figure 1, Figure 2, and Figure 3 are the Gantt charts outlining our planned tasks over the spring, summer, and fall of 2020, respectively.

Project Phase	Leader
Research	Nicholas Chiapputo
Project Definition	Brandon Jones
Specification and Requirements	Tim McCoig
Design and Algorithm Development	Nicholas Chiapputo
Testing and Optimization	Brandon Jones
Prototype Implementation	Samuel Simmons

TABLE III: Leaders for each key project phase.

A. Teamwork

The timeline of the project can be broken into various phases. Although each team member will provide an equal amount of contribution, each will take a lead on a different phase of the project. The key project phases along with leaders of each phase is shown in Table III. The ultimate goal is to be completed with the design of our prototype after the first semester. This will allow for testing and further optimization of the product during the implementation phase. This timeline will also allow extra time for unexpected issues that will arise during implementation.

References

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[9] *Standard for Low-Rate Wireless Networks - Amendment 5: Enabling/Updating the Use of Regional Sub-GHz Bands*, IEEE Standard 802.15.14v-2017, IEEE Computer Society, New York, 2017.

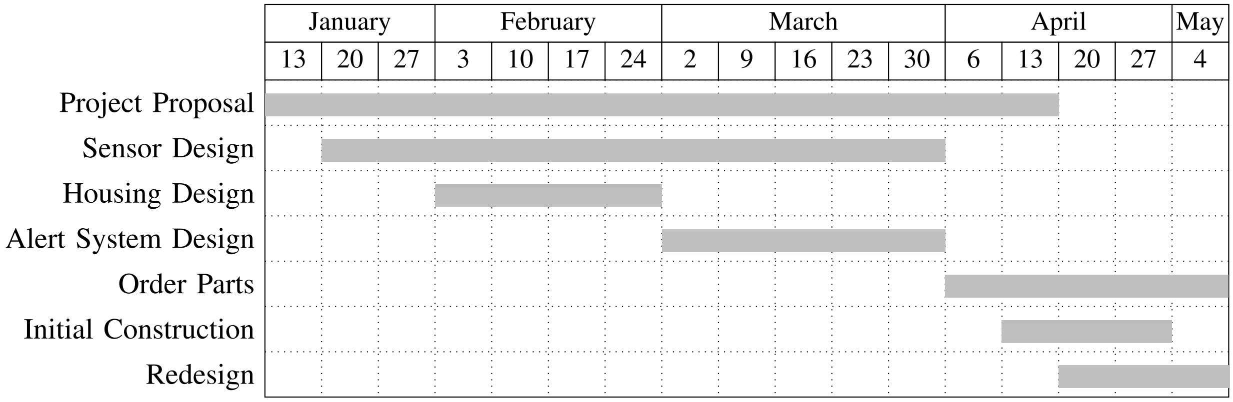

Fig. 1: Tasks for Spring 2020

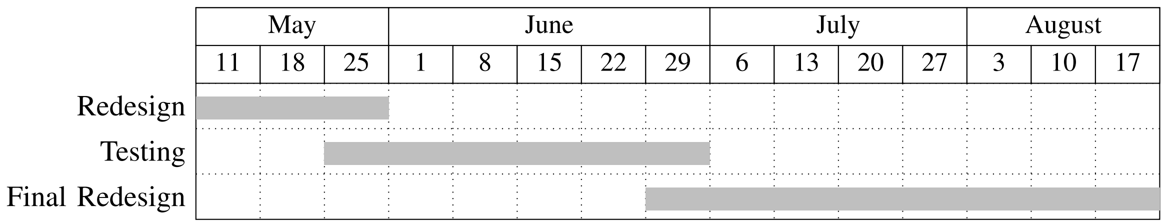

Fig. 2: Tasks for Summer 2020

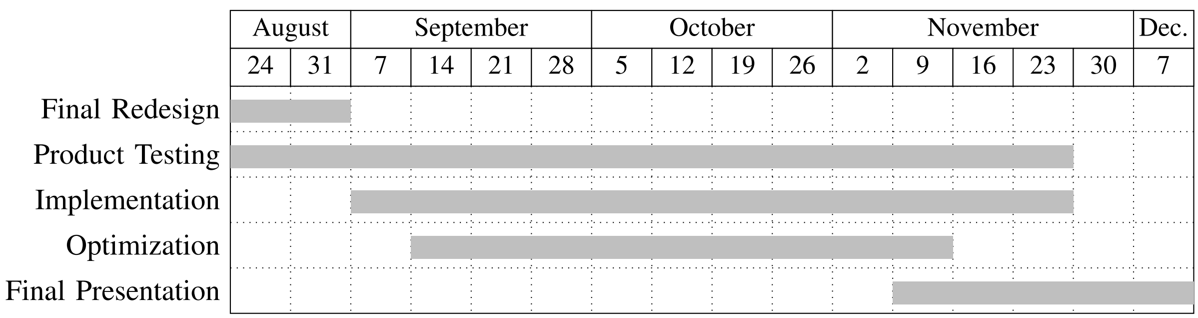

Fig. 3: Tasks for Fall 2020

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