Osprey Demo: A mmWave Approach to Tire Wear Sensing

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ABSTRACT

In this paper, we demonstrate Osprey, a tire wear sensor presented in [4]. Osprey makes use of commodity, automotive, mmWave RADAR, places it in the tire well of automobiles to image the tire and then measures the tire wear. Osprey measures accurate tire wear continuously while being resilient to road debris and without embedding any electronics in tires. Osprey achieves this by building a super resolution algorithm based on Inverse Synthetic Aperture RADAR imaging and by embedding thin metallic strips along coded patterns in the grooves to combat debris. Here, we implement Osprey on a tire rotation rig and demonstrate the ability to measure tire wear (with and without debris) accurately and detect potentially harmful foreign objects.

CCS CONCEPTS

• **Hardware** → **Sensor applications and deployments**; **Sensors and actuators**; **Wireless devices**; **Signal processing systems**; • **Computer systems organization** → **Embedded and cyber-physical systems**; • **Applied computing** → Computers in other domains.

KEYWORDS

Millimeter Wave, Wireless Sensing, Tire Wear, Tread Depth, RADAR, Automotive, 77 GHz, FMCW, Super Resolution, Inverse Synthetic Aperture RADAR Imaging, Debris, Spatial Coding, Orthogonal Codes, Free of Electronics, Foreign Object

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1 INTRODUCTION

This paper describes our proposed demonstration of Osprey [4], a novel solution to sense tire wear continuously even in the presence of debris. Today's solutions are either crude [2], don't measure continuously, are expensive to setup [1], or are susceptible to the accumulation of debris [3].

Osprey overcomes these problems by leveraging commodity, automotive mmWave RADAR and placing it in the tire well, thus allowing for easy, continuous measuring and monitoring of tire wear. Osprey measures the tire wear by analyzing RADAR signals reflected from the tire, estimating the range of the surface and the groove and subtracting the two. Through this demonstration, we will show how Osprey addresses the following two challenges. First, the distance between surface and groove is so small (2 mm - 20 mm) that mmWave RADARs can't resolve reflections from them. Second, even if the surface and groove's reflections are resolved, in the presence of debris, distinguishing the groove from the debris is challenging. Our demonstration of Osprey overcomes these challenges through a super-resolution Inverse Synthetic Aperture RADAR (ISAR) imaging algorithm using the natural rotation of the tire. This ISAR image is used to estimate the surface range. Osprey embeds thin metallic strips in the grooves to emulate a certain spatial code. Using this code, Osprey declutters the reflections from the groove and debris, and estimates the groove range. Osprey then subtracts the surface and groove range to obtain tire wear / tread depth. In addition, Osprey also uses the ISAR image to detect and localize harmful foreign objects such as nails.

We demonstrate the working of Osprey on a tire rotation rig. We show the measurement of tire wear with and without debris, and the detection of foreign metallic objects.

Demo URL: https://www.witechlab.com/osprey.html

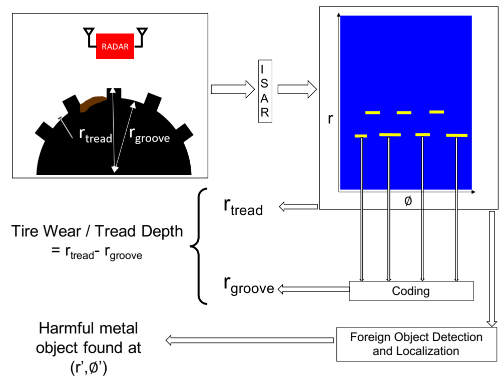

Figure 1: Osprey's Overview: (1) Generate a super-resolution Inverse Synthetic Aperture RADAR (ISAR) image. Obtain $r_{\mathbf{tread}}$ from the image (2) Isolate groove from debris using coding to obtain $r_{\mathbf{groove}}$. Subtract $r_{\mathbf{tread}}$ and $r_{\mathbf{groove}}$ to obtain tire wear / tread depth (3) Detect and locate foreign objects using ISAR image.

2 SYSTEM OVERVIEW

Osprey's sensing system consists of 3 main parts (see Fig. 1):

Super-resolution algorithm and tire surface ranging: In order to separate the reflections from the surface and the groove of the tire tread, we design a super-resolution ISAR algorithm which overcomes the limited range and azimuth resolution of the RADAR.

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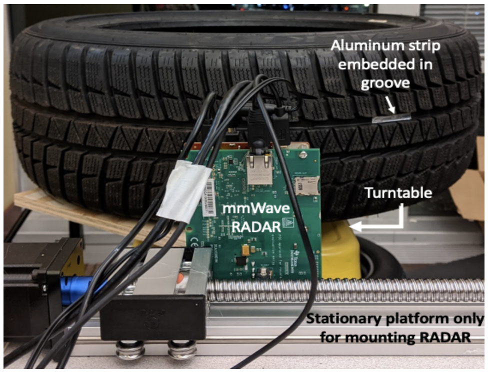

Figure 2: Osprey tire rotation rig: The tire, with one bit of Aluminium strip embedded in central groove, is mounted on a turntable controlled by stepper motors. mmWave RADAR is mounted at a distance on a table, and streams I/Q samples to computer.

Intuitively, the algorithm uses the circular trajectory of rotation, collects and coherently processes multiple signals reflected from the tire during its rotation. Specifically, Osprey constructs a received signal model for every point on the tire throughout its trajectory. To image that point, Osprey projects the received signal onto the signal model to obtain the pixel value of the ISAR image corresponding to that point. The tire's tread patterns are observed in the ISAR image. Osprey then chooses r_{tread} such that the tread patterns are in sharp focus.

Debris resilient groove ranging: The presence of debris will result in inaccurate groove ranges. To separate the groove from the debris, Osprey places simple metallic strips (chosen so that they reflect more than the debris) along the circumference of the tire, in the groove, in coded patterns. To maximize the reflectivity from the metallic strips, they are used to encode both 0 and 1, using pulse width modulation. These coded patterns emulate a spatial code which is unique to the groove's position. Osprey searches over r to find r_{groove} such that the spatial codes are in sharp focus. Tire wear is obtained by simply subtracting r_{tread} and r_{groove}.

Foreign object detection: Osprey uses the ISAR image to detect harmful metallic foreign objects such as nails. Based on the ISAR pixel value, the detector either classifies as harmful metallic or non-harmful.

3 DEMO SETUP

We demonstrate Osprey on a tire rotation rig (see Fig. 2). The rig comprises of a turntable driven by a Nema 23 stepper motor and a microstepping driver controlled by a microcontroller. The turntable provides a platform to mount the tire. We mount passenger car sized tires and rotate at safe speeds of upto 5.45 kmph. We implement Osprey on 77-81 GHz automotive RADAR - TI AWR1642BOOST. We interface the RADAR with DCA1000EVM, an FPGA board which streams raw I/Q samples to the computer running the algorithm. Osprey embeds tiny, Aluminium strips in grooves of tires to provide resilience to debris. For our demo, we rotate the tire at fixed speed while simultaneously collecting the signal from the RADAR and processing on a computer using Osprey's algorithm.

Figure 3: Demonstration of Osprey's effectiveness in measuring tire wear in the presence of debris using metallic codes.

We will demonstrate three aspects of Osprey as follows:

Tire Wear Measurement: We compute the tire wear using Osprey's algorithm and compare it with the measurement from a Vernier caliper. The demo also shows the intermediate ISAR image which clearly shows the tread patterns and the metallic strips embedded in grooves as pixels of high energy.

Tire Wear Measurement in the presence of debris: We compute the tire wear when some and all of the metallic strips are covered in debris (sawdust) (see Fig. 3). We compare our measurements with that from a laser range finder and show the ineffectiveness of laser. The influence of debris on the ISAR image is also shown in the demo.

Foreign Object Detection: We demonstrate how Osprey detects foreign objects such as nails. We place nails in the tire at random locations and observe its impact on the ISAR image. The detector uses the ISAR image to classify harmful metal vs non harmful foreign objects.

4 CONCLUSION

We demonstrate Osprey, a tire wear sensor system presented in [4]. We implement Osprey on a mmWave RADAR platform and demonstrate it on a tire rotation rig. The demonstration includes showcasing the ability of Osprey to perform tire wear measurements with and without debris and also to detect harmful foreign objects in the tire.

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