Demo Abstract: Cognisense: A contactless rotation speed measurement system

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ABSTRACT

Several engineering applications require reliable rotation speed measurement for their correct functioning. The rotation speed measurements can be used to enhance the machines' vibration signal analysis and can also elicit faults undetectable by vibration monitoring alone. The current state of the art sensors for rotation speed measurement are optical, magnetic and mechanical tachometers. These sensors require line-of-sight and direct access to the machine which limits their use-cases. In this demo, we showcase Cognisense, an RF-based hardware-software sensing system that uses Orbital Angular Momentum (OAM) waves to accurately measure a machine's rotation speed. Cognisense uses a novel compact patch antenna in a monostatic radar configuration capable of transmitting and receiving OAM waves in the 5GHz license-exempt band. The demo will show Cognisense working on machines with varied numbers of blades, sizes and materials. We will also present how Cognisense operates reliably in non-line-of-sight scenarios where traditional tachometers fail. We demonstrate how Cognisense works well in high-scattering scenarios and is not impacted by the material of rotor blades. Unlike optical tachometers that require one to face the machine head-on, Our demo will also show Cognisense performing reliably in the presence of a tilt angle between the system and the machine which is not possible with optical tachometers.

CCS CONCEPTS

• **Hardware** → *Sensor devices and platforms*; Sensors and actuators; **Digital signal processing**; • **Computer systems organization** → Sensors and actuators.

KEYWORDS

Rotation Monitoring, Orbital Angular Momentum, RF Sensing

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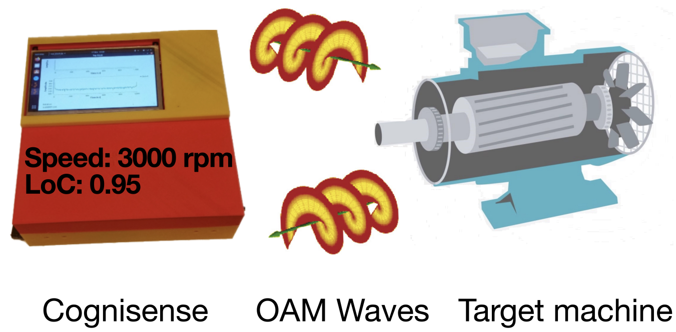

Figure 1: Cognisense Operating Principle

1 INTRODUCTION

Condition monitoring of rotating machines has traditionally used vibration-based sensing which is not ideal as vibration signals exhibit a cyclo-stationary behaviour coupled to the rotation cycle of the machine [3]. This behaviour implies that the rotation speed is needed to enhance the vibration signal's extraction and analysis [4]. Additionally, measuring the speed enables detection of local emerging internal component failures, such as gear teeth wear or cracks, which are undetectable using vibration sensors [1]. As a result measuring the rotation speed is crucial to understanding the nominal performance and predict any possible future failures [5]. Mechanical, optical and magnetic tachometers are the state-of-art for accurate rotation speed measurement. These technologies have four constraints that make them inappropriate for a cost-effective practical deployment. Firstly, they require direct contact or a short separation distance (mm) between the machine and sensor or a line-of-sight path between the tachometer and the rotating shaft. Secondly, mounting or installing a sensor, reflective tape, or tag on the machine body is impractical in online monitoring scenarios and increases machine stoppage hours. Third, foreknowledge of machine shape (e.g. number of rotating blades) is a requirement in magnetic tachometers. Fourth, magnetic tachometers require rotating objects to be built with ferrite materials.

All the above constraints lead us to create Cognisense. Cognisense is a non-intrusive wireless machine monitoring platform that exploits the rotational frequency Doppler shift principle to measure a machine's rotation speed. Cognisense is a hardware radar sensor, along with a novel signal processing algorithm. It is the first RF-based rotation monitoring sensor and does not require a line-of-sight to the rotating machine or prior knowledge about the machine's material or number of rotating blades. It also supports a 180° detection angle and detection range of > 1 meter depending on the transmitter's output power. The novel signal processing algorithm can estimate the speed of a rotating machine amidst environmental RF noise and harmonics from a machine's blades.

In this demo, we will showcase Cognisense's ability to work on machine's with different materials and number of blades. We will also showcase Cognisense's performance in high scattering and non-line-of-sight (NLOS) environments. Finally, we will show how we use our novel multi-carrier sensing algorithm to achieve a higher rotation speed resolution.

2 COGNISENSE OVERVIEW

Fig. 1 shows Cognisense's operating principle. Cognisense continuously transmits orbital angular momentum (OAM) waves towards a rotating machine in a specific frequency band using a multi-subcarrier signal composed of N subcarriers. When the OAM waves are incident on the rotating machine, every subcarrier undergoes rotation Doppler shift, and its frequency is shifted and reflected. The OAM waves are then received through Cognisense's receiver OAM antenna. Cognisense's signal processing algorithm isolates the received signal from the background noise by adjusting the receiver threshold value. The isolated signal is fed through our proposed advanced detection algorithm that is composed of two main parts: 1) demodulation part for each subcarrier, and 2) multicarrier level of confidence (LoC) part for N subcarriers. The output of the advanced detection algorithm is the rotation speed and LoC values. The main components of Cognisense are summarised below.

2.1 OAM radar sensor antennas

We propose the first OAM antenna operating in a *monostatic radar configuration* for rotation sensing applications. The antennas have to be in a monostatic radar configuration, i.e. transmitter and receiver antennas are next to each other, to allow the system to have a small form-factor suitable for industrial deployments. The antennas operate in the 5GHz license-exempt band to ease their deployments in industrial scenarios. The dimensions of the antenna are $50mm \times 50mm$ and 1 mm thickness. Linearly polarised antennas suffer from depolarisation in high scattering multipath environments [2] which is mitigated by the use of OAM antennas, making them appropriate for RF sensing applications.

2.2 Demodulation detection algorithm

The demodulation process extracts the desired signal from the carrier signal. In our case, we want to extract the fundamental Doppler frequency shift (Δf) from the received OAM wave in the presence of other frequency harmonics and background noise. First, we convert the signal to the frequency domain with FFT and remove the background noise through a threshold filter. Next, we identify the local maximas in the filtered signal and calculate Δf knowing two important features of the fundamental frequency of rotation: 1) Δf should occupy the lowest harmonic order in the received signal spectrum, 2) Every two successive harmonics are separated by a frequency band equal to Δf. Finally, a probability distribution function (pdf) is created for all possible values of Δf and Δf with the highest pdf is selected.

2.3 Multicarrier level of confidence (LoC) detection algorithm

Every subcarrier individually has a resolution of 60rpm and so with only 1 subcarrier the rotation speed can be measured with a resolution of 60rpm. We use N subcarriers to get a higher resolution for the measured rotation speed. The N subcarriers exhibit different channel path loss that causes the scattered signal from the machine to be received at different phases. This phase diversity in signal reception leads to a better estimation of the fundamental frequency and increases Cognisense's resolution to $60/N$. However, if majority of the subcarriers do not report similar speeds, the confidence on the value is low as high-scattering environments also have an influence on the phase change. To evaluate the accuracy of the reported speeds, the system outputs LoC along with the measured speed. LoC is the probability that the variation in the measured fundamental frequency in the N subbands is ± 1 Hz. The LoC can be improved by varying the transmit power and the receiver signal threshold.

3 DEMONSTRATION

In this demo, we will showcase Cognisense's various capabilities. Cognisense's setup consists of a software defined radio connected to two OAM antennas (TX/RX pair). In the demo, we will compare the performance of our designed OAM antennas against the performance of linearly polarised antennas in the same frequency band. The comparison will show the necessity for the use of OAM antennas in high scattering environment. Next, we will demonstrate the sensing capability of Cognisense in NLOS scenarios where conventional optical tachometers fail, e.g. we will show how Cognisense can measure the rotation speed of a machine inside non-metallic enclosure, or when the machine is not aligned with Cognisense. Finally, we will show how Cognisense works on machines made of different materials and varied number of blades.

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