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Application of Machine Learning Technique for Development of Indirect Tire Pressure Monitoring System

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Abstract

Tire inflation pressure has a significant impact over vehicle driving dynamics, fuel consumption as well as tire life. Therefore, continuous monitoring of tire pressure becomes imperative for ride comfort, safety and optimum vehicle handling performance. Two types of tire pressure monitoring systems (TPMS) used by vehicles are - direct and indirect TPMS. Direct systems deploy pressure sensors at each wheel and directly send pressure value to the vehicle Controller Area Network (CAN). Indirect sensors on the other hand use the information from already existing sensors and some physics-based equations to predict the value of tire pressure. Direct TPMS tend to be more accurate but have higher cost of installation while indirect TPMS comes with a minimum cost but compromised accuracy.

A digital proof-of-concept study for indirect TPMS development of a non–ESP vehicle based on machine learning (ML) technique is elaborated in this paper. The study aims to propose a methodology for development of an indirect TPMS having an accuracy equivalent to that of a direct TPMS. A full vehicle model designed in Amesim software is used to extract data to train the machine-learning algorithm for different test cases. Simulation model is validated against the test data of vehicle dynamics parameters to ensure the accuracy of data extracted for ML model training. Multilayered feed forward, back-propagation artificial neural network is trained using three prediction algorithms and sensitivity of different algorithms, network parameters is analyzed against selected driving scenarios.

Proof-of-concept study suggests that the proposed tire pressure prediction algorithm has a potential to predict tire pressure accurately at par with Direct TPMS. It lays a foundation for developing ML based indirect TPMS using physical testing data by providing assistance in test plan preparation, exploring data pre-processing techniques and algorithm selection. Furthermore, the generic methodology mentioned in this paper can be referred for initial development of any ML based project.

Introduction

vehicles up to a maximum weight of 3.5 T manufactured after Oct, 2020.

Owing to safety, handling and driving performance, TPMS becomes an important feature for vehicles. There are two types of TPMS- direct and indirect. Direct TPMS uses the sensors mounted on tire rim to measure the inflation pressure while indirect TPMS predicts the value of pressure based on other vehicle parameters. Pressure prediction methods deployed by indirect TPMS might be based on some physics-based model or it can be data driven. Data driven method make use of various mathematical models to find a pattern between tire pressure and vehicle parameters depending upon the data provided. Out of the two kinds of TPMS, direct TPMS has a higher cost of installation while indirect TPMS may have very less accuracy if not modeled cautiously.

This paper is based on data driven approach to indirect TPMS which uses machine learning model to map the relation between input parameters and tire pressure. Machine learning refers to a set of algorithms that learn and improve without being explicitly programmed. Availability of large amount of data and ability of these algorithms to find the hidden patterns in complex data has resulted in making machine learning an emerging field in automotive industry.

Arthur B. et. al. [1] studied the effect of tire inflation pressure over fuel consumption and rolling resistance based on Simulink model fed with experimental data. Results of this study indicated Improvements up to 50% in fuel consumption at 120km/h while rolling resistance force showed reduction up to 80% on increasing inflation pressure. Fredrik G. et. al. [4] mentioned two classes of tire pressure prediction methods- Vibration analysis and wheel radius analysis. The former analysis method relates tire resonance frequency to pressure while the latter is based on the fact that tire's rolling radius is the direct indicator of pressure. Jian Z. et. al. developed an indirect TPMS based on tire resonance frequency analysis using maximum entropy spectral emission based on auto-regressive model [5]. This model was validated against test data and it was found that tire deflation can be indicated by a decrease in resonance frequency. Katsuhiko Iwazaki and Isahiko Tanaka [10] deployed a smart algorithm based on disturbance observer using least mean square error and comparative analysis of tire