Proceedings of the Canadian Society for Mechanical Engineering International Congress 2022
CSME Congress 2022
June 5-8, 2022, Edmonton, AB, Canada

Deep Learning and Nonlinear Model Predictive Control Integration for Compression Ignition Engine Emission Reduction

Armin Norouzi[1*], Saeid Shahpouri[1], David Gordon[1], Alexander Winkler[2], Eugen Nuss[3], Jakob Andert[4], Mahdi Shahbakhti[1], Charles Robert Koch[1]

[1]Mechanical Engineering Department, University of Alberta, Edmonton, Canada
[2]Teaching and Research Area Mechatronics in Mobile Propulsion, RWTH Aachen University, Germany
[3]Institute for Automatic Control, RWTH Aachen University, Germany
*norouziy@ualberta.ca

1. ABSTRACT

Internal Combustion Engines (ICEs) are used on a broad range of equipment due to their reliability and lifespan. However, the widespread use of the ICE has resulted in over 20% of the total greenhouse gas (GHG) emissions worldwide. With increasing stringent worldwide regulations, engine controllers that optimize the combustion subject to constraints are becoming increasingly complex . Model Predictive Controller (MPC) is a promising method for the systematic optimization of ICEs as it can regulate highly constrained nonlinear systems and achieve multi-objective functions of time-critical systems. As with other model-based control systems, the MPC control performance is directly correlated to the accuracy of the embedded plant model. To improve control performance, a more accurate model is needed but this greatly increases the computational requirements for implementation. Even with the vast improvements in the processing power of microcontrollers, there are still limitations of MPC implementation in real-time applications. To address these MPC challenges, machine learning (ML) can be integrated with MPC.

The objective of this study is to demonstrate how machine learning (ML) and nonlinear model predictive control (NMPC) can be used to reduce the emissions and fuel consumption of a compression ignition engine. ML can be used to identify accurate models for use in MPC implementation. In this study, the emissions and performance of a compression ignition engine are modeled using a deep recurrent neural network using long-short-term memory (LSTM) layers. This model is then used to design a model predictive controller with improved accuracy and reduced computational requirements. In addition to using ML for modeling, it can also be used to replace a MPC by mimicking its behavior by learning the best control action. This is then used to further reduce the computational requirements of the MPC. In this study the MPC is imitated using an innovative deep learning approach where the LSTM is integrated to the network's hidden and cell states in an NMPC optimization problem. A physics based Engine Simulation Model (ESM), a GT-power/MATLAB, has been developed and parameterized with experimental data. The LSTM-NMPC and the Imitative NMPC are then compared to a calibrated production ECU model in simulation using the ESM. While tracking a desired engine load, the LSTM-NMPC controller has a considerable reduction in NOx emissions and a slight reduction in fuel usage. The Imitative NMPC achieves comparable performance to the LSTM-NMPC but achieves a two-order-of-magnitude reduction in computational time.

Word count: 395