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THE UNIVERSITY OF BRITISH COLUMBIA

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MECH 493 project: Development of a Machine-Learning Algorithm for Combustion Image Analysis

Background and research goal

Under a sustainable development scenario where global temperature rise is limited to less than 2°C, the transportation sector is forecasted to become the single greatest contributor to greenhouse gas (GHG) emissions by the 2030s [1]. This points to the difficulty in decarbonizing certain subsectors, such as heavy-duty transportation (e.g. long-haul trucking and marine) where direct electrification is not feasible and demand is expected to grow significantly [1,2]. Renewable and/or low-carbon gaseous and bio-fuels are considered a promising avenue for addressing GHG and pollutant emissions in heavy-duty direct-injection engines in the near term, while supporting the development of zero-carbon (e.g. hydrogen) solutions for the long-term. Characterizing fluid mixing and combustion processes relevant to gaseous direct-injection engines is a fundamental component of supporting the development of these alternative fuel technologies.

At UBC's Clean Energy Research Centre (CERC), several high-speed imaging diagnostics are applied to the measurement and analysis of gaseous fuel jets and internal combustion systems: i) In-cylinder OH*-chemiluminescence (OH*-CL) and natural luminosity (NL) imaging for characterization of ignition and combustion, and ii) Background oriented schlieren (BOS) and traditional schlieren for measurement of gaseous fuel jet penetration and mixing. These imaging diagnostics provide rich field data (i.e. as opposed to point measurements) as a function of time (i.e. an image series). However, quantified analysis of this data requires image segmentation and automated feature extraction, which is challenging for traditional image processing algorithms. Application of machine learning techniques (e.g. convolutional neural networks, CNN) are of interest as an approach for automated segmentation and analysis of these rich data sets. The proposed MECH 493 project has two main objectives: i) development of a general procedure and software toolkit for application of machine learning techniques (e.g. CNN) to the analysis of OH*-CL, NL, BOS, schlieren images, and ii) comparison of the performance (feature extraction robustness, computational cost) of a CNN against traditional image segmentation algorithms.

Proficiency with MATLAB scripting and image processing toolbox is mandatory. Experience with Python scripting is an asset.

Tasks to be performed by the student

- General literature review of state-of-the-art reaction zone characterization for in-cylinder imagine; Literature review and critical comparison of existing machine-learning methods applied to image segmentation (student is expected to identify methods used in fields outside of combustion research); identification of an optimal approach for existing combustion image data sets
- Develop a toolkit (Matlab or Python) for the implementation of a machine-learning algorithm to in-cylinder combustion images (OH*-CL and NL). It is expected that existing toolkits (e.g., TensorFlow) may be applied.
- Compose a white paper on the practical application of the developed machine-learning toolkit for combustion image segmentation (including training data sets, labelling, CNN design, etc.).
- Perform a critical and quantified comparison of the performance of the developed image segmentation tool(s) and existing segmentation algorithms.
- Document the toolkit development, implementation, and validation in a manner suitable for submission to a scientific journal and/or conference.

Facilities and team:

This project will be carried out within the Clean Energy Research Center (CERC), in the Engine and Combustion Research Group. The activities will be supervised by Dr. Kirchen, though the student will be integrated into the research group and is expected to collaborate with graduate students working in the area of natural gas engines and optical diagnostics. It is expected that the bulk of the research activities can be performed using existing datasets, and additional dedicated measurements will not be required. Progress meetings will be held every ~2 weeks, however more frequent informal meetings will be possible as required.

References:

[1] International Energy Agency. World Energy Outlook 2019. 2019.

[2] S. Gross. The challenge of decarbonizing heavy transport. Technical report, Brookings Institute, 2020.