MIE498H1: Research Thesis 2025-2026

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Number of Positions	1
Open to	Mechanical Engineering Students
Term Offered	Full-year
Research Area	Thermofluids
Research Topic	AI Segmentation of Turbulent Flow Structure

Project Description

This thesis investigates the application of artificial intelligence-based image segmentation techniques to enhance the analysis of turbulent flow structures in particle image velocimetry (PIV) experiments. Traditional masking approaches in PIV preprocessing rely on either void region identification or manual masking procedures, both of which present significant limitations in terms of efficiency and adaptability. Manual masking becomes prohibitively time-consuming when dealing with dynamic experimental conditions, such as varying airfoil pitch angles during particle image velocimetry (PIV) sampling. In contrast, automated void region identification methods often fail to delineate complex geometric boundaries accurately. Recent advancements in computer vision, particularly the development of foundation models such as the Segment Anything Model (SAM) by Meta AI, offer promising solutions for complex segmentation challenges across various engineering applications. While SAM can accept various prompting forms, including points and bounding boxes, complex aerodynamic geometries, such as multi-element airfoils and flaps, require more sophisticated prompting strategies. This research proposes integrating SAM with natural language processing models, specifically BERT (Bidirectional Encoder Representations from Transformers) developed by Google, to provide detailed, contextually aware prompts for automated PIV preprocessing tasks. The integrated framework will enable the AI model to perform specific PIV preprocessing operations, including mask generation, image concatenation, and size adjustment, while accommodating time-varying experimental conditions through dynamic masking capabilities. The methodology involves developing a unified system that accepts high-level descriptions of experimental configurations and translates these into appropriate segmentation prompts, validated against both synthetic and experimental PIV datasets. Expected contributions include a novel application of foundation models to experimental fluid mechanics, development of natural language-guided segmentation for complex geometries, and creation of an automated preprocessing pipeline that significantly reduces manual intervention requirements. The research timeline spans two academic terms, with initial AI model implementation and synthetic validation in the first term, followed by experimental validation and performance optimization in the second term. This work demonstrates the transformative potential of integrating advanced AI technologies with experimental fluid mechanics workflows, addressing long-standing challenges in PIV analysis while establishing a framework for broader adoption of AI-enhanced methodologies in engineering research applications.

Application Instructions	Please submit CV and unofficial transcript to pierre.sullivan@utoronto.ca