FAU COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
FLORIDA ATLANTIC UNIVERSITY

Announces the Ph.D. Dissertation Defense of

# ERIC B. JAGODINSKI

for the degree of Doctor of Philosophy (Ph.D.)

## "Data-driven Identification and Control of Turbulent Structures using Deep Neural Networks"

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SeaTech, Room: ST259
101 North Beach Road,
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ABSTRACT OF DISSERTATION

Wall-bounded turbulent flows are pervasive in numerous physics and engineering applications. Such flows tend to have a strong impact on the design of ships, airplanes and rockets, industrial chemical mixing, wind and hydrokinetic energy, utility infrastructure and innumerable other fields. Understanding and controlling wall-bounded turbulence has been a long-pursued endeavor yielding plentiful scientific and engineering discoveries, but there is much that remains unexplained from a fundamental viewpoint. One unexplained phenomenon is the formation and impact of coherent structures like the ejections of slow near-wall fluid into faster moving flow which have been shown to correlate with increases in friction drag. This thesis focuses on recognizing and regulating organized structures within wall-bounded turbulent flows using a variety of machine learning techniques to overcome the non-linear nature of this phenomenon.

Deep Learning has provided new avenues of analyzing large amounts of data by applying techniques modeled after biological neurons. These techniques allow for the discovery of non-linear relationships in massive, complex systems like the data found frequently in fluid dynamics simulation. Using a neural network architecture called Convolutional Neural Networks that specializes in uncovering spatial relationships, a network was trained to estimate the relative intensity of ejection structures within turbulent flow simulation without any a-priori knowledge of the underlying flow dynamics. To explore the underlying physics that the trained network might reveal, an interpretation technique called Gradient-based Class Activation Mapping was modified to identify salient regions in the flow field which most influenced the trained network to make an accurate estimation of these organized structures. Using various statistical techniques, these salient regions were found to have a high correlation to ejection structures, and to high positive kinetic energy production, low negative production, and low energy dissipation regions within the flow. Additionally, these techniques present a general framework for identifying nonlinear causal structures in general three-dimensional data in any scientific domain where the underlying physics may be unknown.

While identification is an important goal, control and regulation of these coherent structures has countless scientific and practical applications, like modulating drag on ships or efficiency in utility infrastructure. However, control of turbulent flows has been a challenging problem because of the inherent nonlinear evolution of the coherent structures. Deep Reinforcement Learning may help overcome these obstacles by leveraging artificial neural networks to devise an effective control scheme, even without a-priori knowledge of the underlying dynamics. The proposed approach is to utilize Deep Reinforcement Learning for control of blowing-suction actuators within a wall-bounded turbulent simulation with the goal of friction drag reduction. Preliminary results aiming to reduce the intensity of ejection structures with a simple representation of the

flow field achieved a notable reduction in the intensity.A framework to expand upon this control scheme has been developed in which two-dimensional Convolutional Neural Networks were used to reveal spatial patterns, and Long Short-Term Memory was used to reveal temporal relationships in the in the flow history. This framework can be used to uncover causal relationships between the autonomously determined actuation policy and the subsequent influence on the turbulent flow state.

BIOGRAPHICAL SKETCH
Born in Boca Raton, Florida, USA
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CONCERNING PERIOD OF PREPARATION
& QUALIFYING EXAMINATION

**Time in Preparation:** 2017 - 2022

**Qualifying Examination Passed:** Fall 2018

**Published Papers:**

Eric Jagodinski, Siddhartha Verma. “Convolutional Neural Networks for Identifying Coherent Turbulent Structures”. In Bulletin of the American Physical Society, Volume 64, Seattle 2019

Eric Jagodinski, Siddhartha Verma. “Data-Driven Blowing-Suction Control in a Turbulent Channel Flow”. In Bulletin of the American Physical Society, Volume 66, Phoenix, 2021

Eric Jagodinski, Xingquan Zhu, Siddhartha Verma. “Data-Driven Intentification of dynamically important regions in turbulent flows using 3D Convolutional Neural Networks”. (Under review)