# Digital Twinning of Mechatronic Systems for Control and Fault Diagnosis

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Research Website

Ulster University

## Digital Twin of an Automotive Engine System

VOLVO · LINKÖPING UNIVERSITY · MONASH University
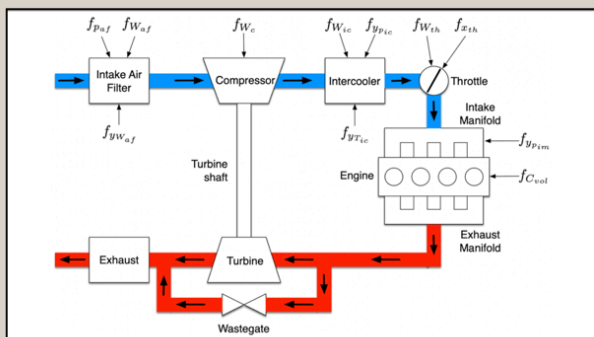
Physical Automotive Vehicle
volvocars.com

Understanding of Engine Dynamics
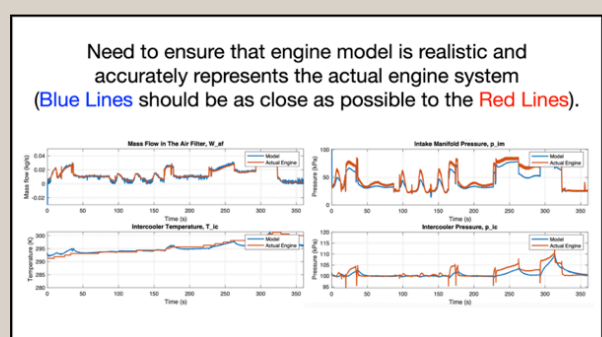volvocars.com

Identifying Faults of Interest
Ng et al., IEEE CSM, 2020.
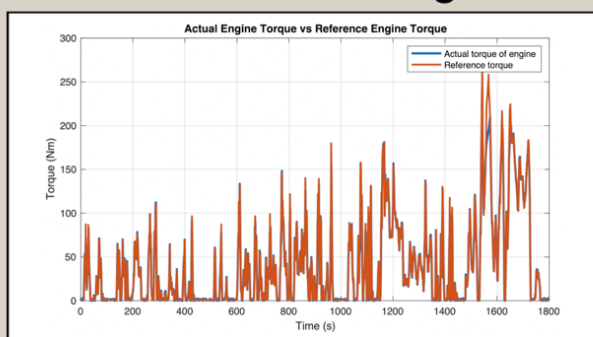
Verification of Engine Model and Controller Design
Need to ensure that engine model is realistic and accurately represents the actual engine system (Blue Lines should be as close as possible to the Red Lines).
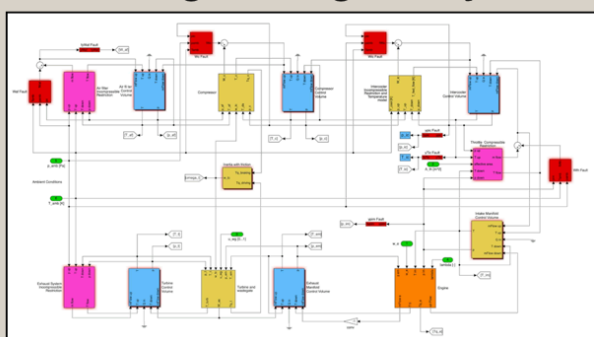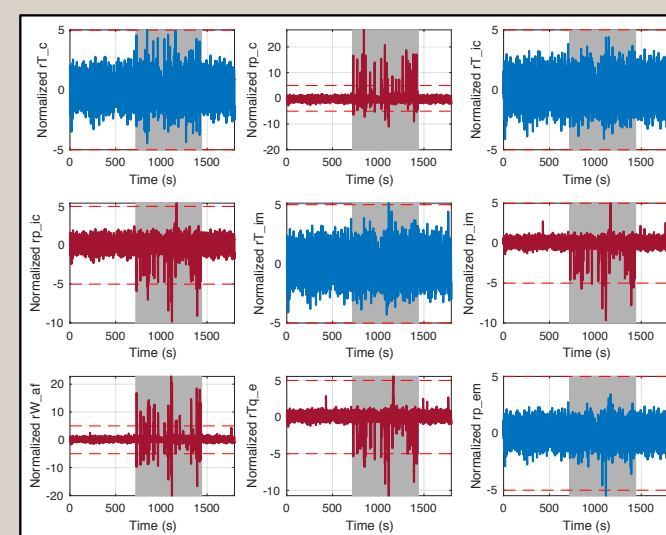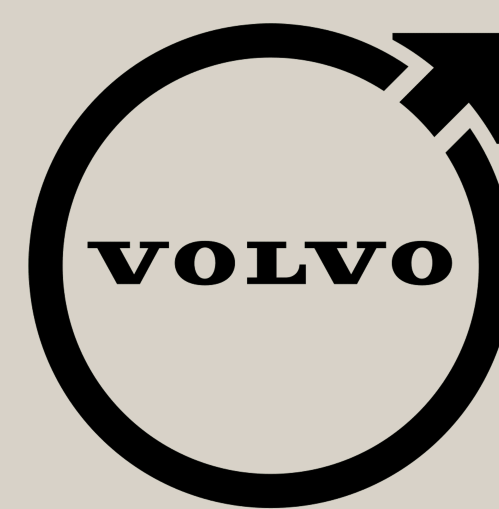Ng et al., IEEE CSM, 2020.

Controller Design
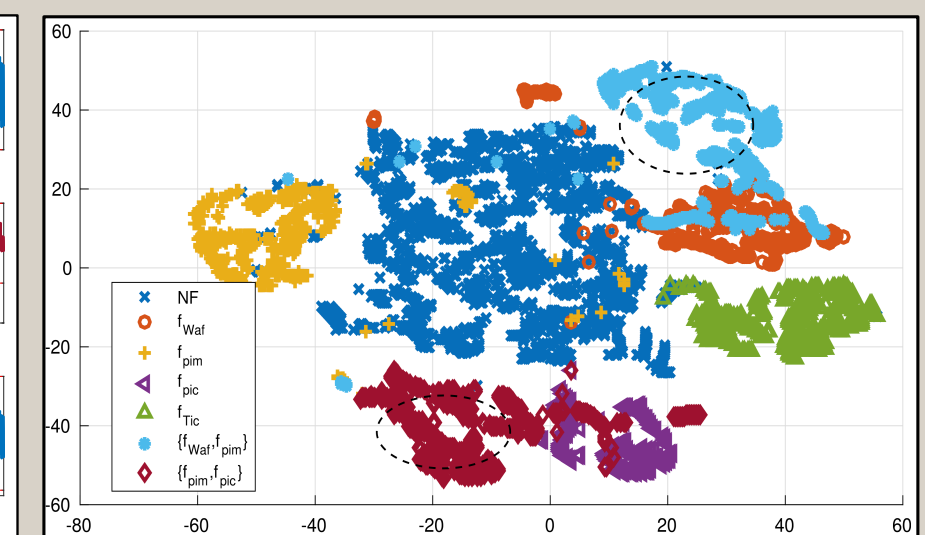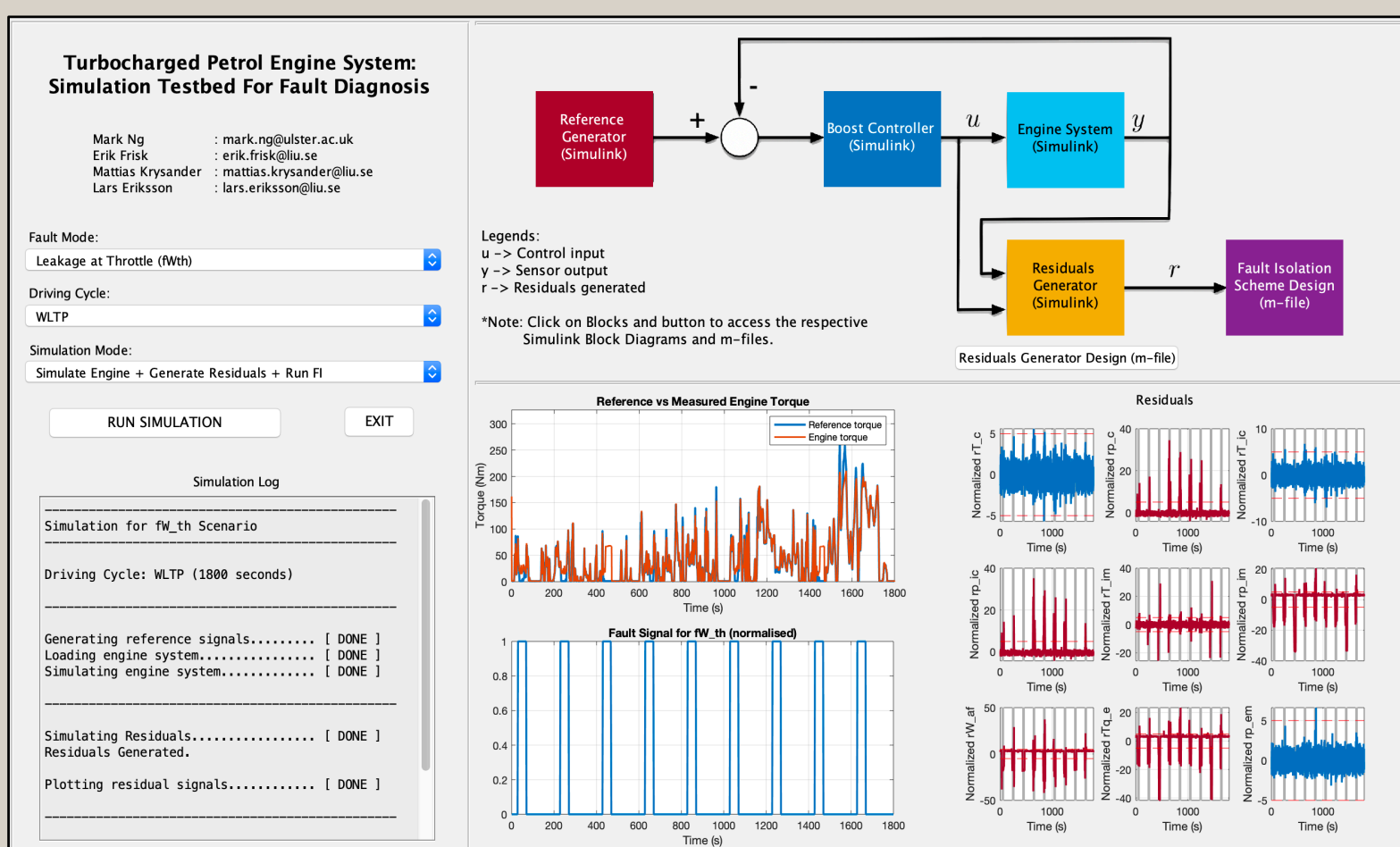Ng et al., IEEE CSM, 2020.
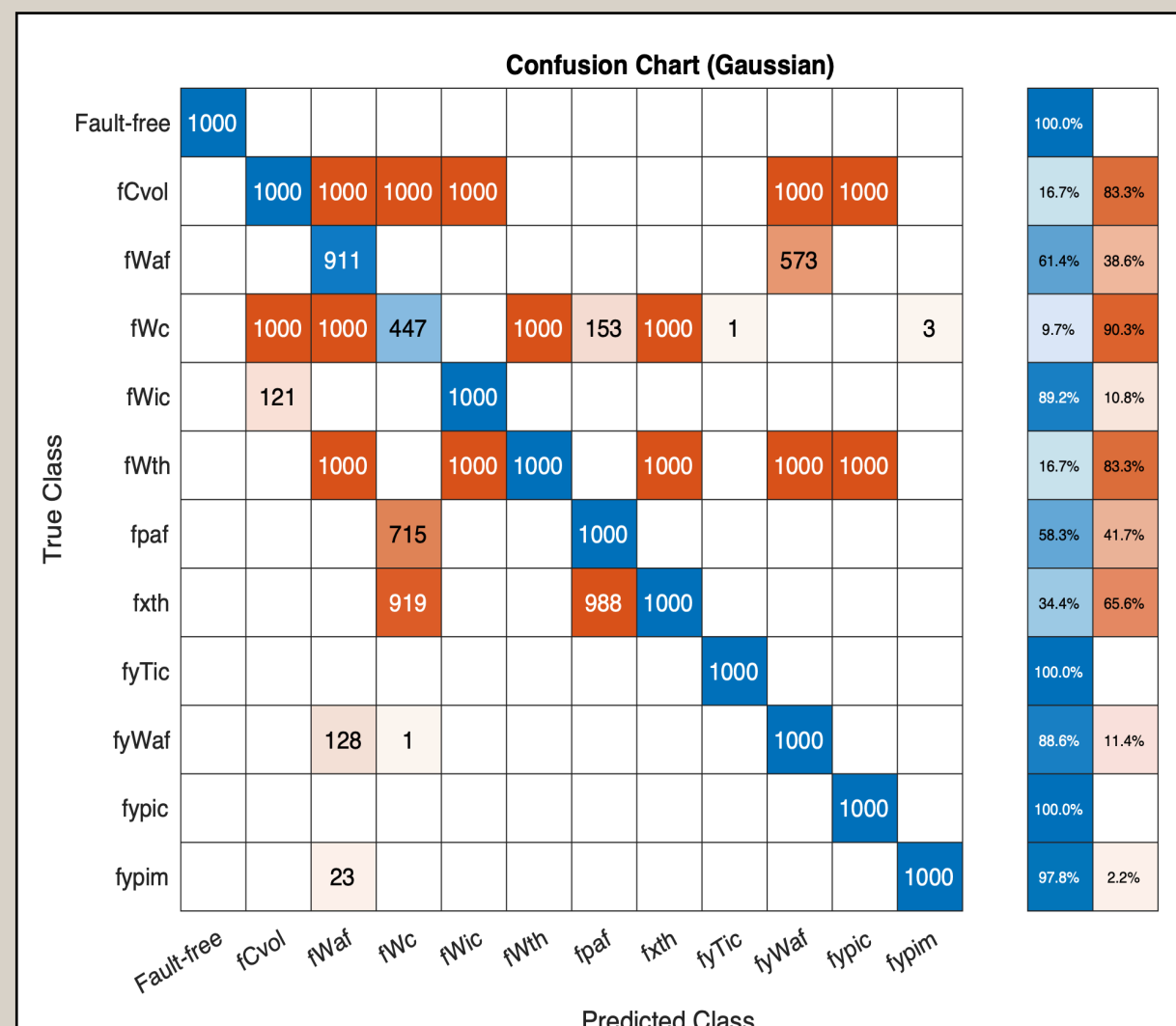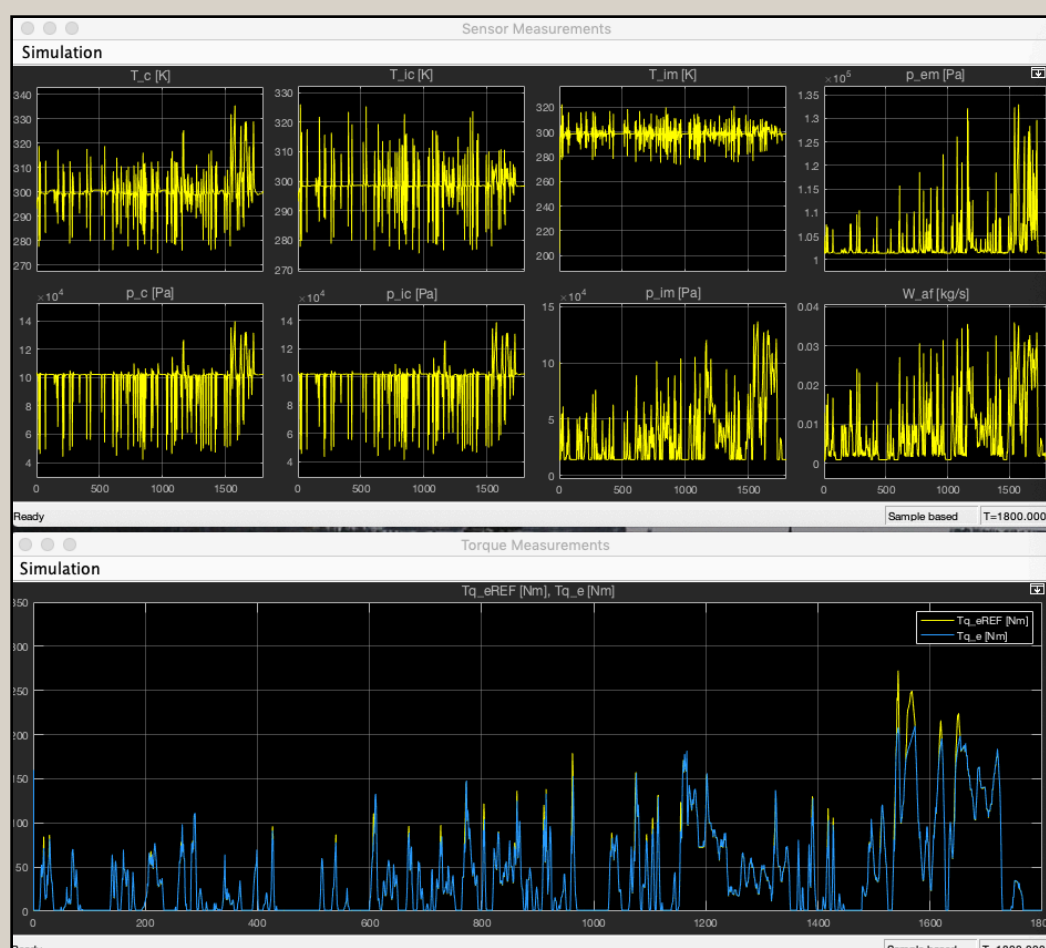
Modeling of Engine System
Ng et al., IEEE CSM, 2020.

Residuals Analysis

Multidimensional Data Analysis

Turbocharged Petrol Engine System:
Simulation Testbed For Fault Diagnosis

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Fault Mode:
Leakage at Throttle (fWth)
Driving Cycle:
WLTP
Simulation Mode:
Simulate Engine + Generate Residuals + Run FI

RUN SIMULATION    EXIT

Simulation Log

Simulation for fW_th Scenario

Driving Cycle: WLTP (1800 seconds)

Generating reference signals......... [ DONE ]
Loading engine system................ [ DONE ]
Simulating engine system............. [ DONE ]

Simulating Residuals................. [ DONE ]
Residuals Generated.

Plotting residual signals............ [ DONE ]

Legends:
u -> Control input
y -> Sensor output
r -> Residuals generated

*Note: Click on Blocks and button to access the respective Simulink Block Diagrams and m-files.

Reference Generator (Simulink) · Boost Controller (Simulink) · Engine System (Simulink) · Residuals Generator (Simulink) · Fault Isolation Scheme (m-file)

Residuals Generator Design (m-file)

Reference vs Measured Engine Torque · Residuals · Fault Signal for fW_th (normalised)

Simulation GUI and Telemetry Visualizations

Confusion Chart (Gaussian)

Classification and Diagnosis

GitHub
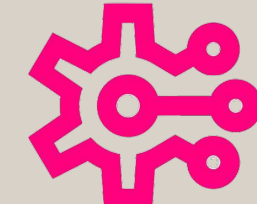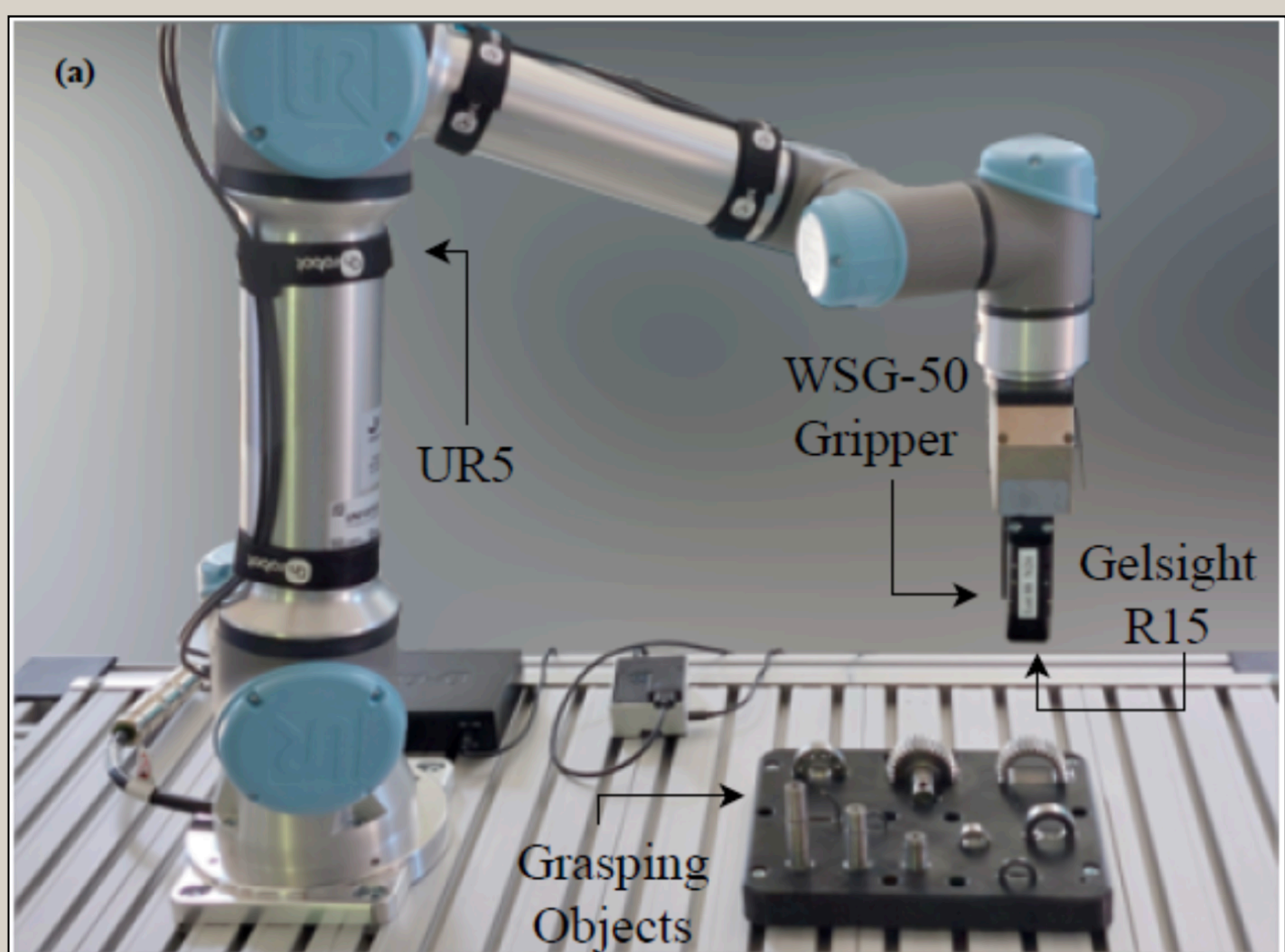
IEEE CSM Paper

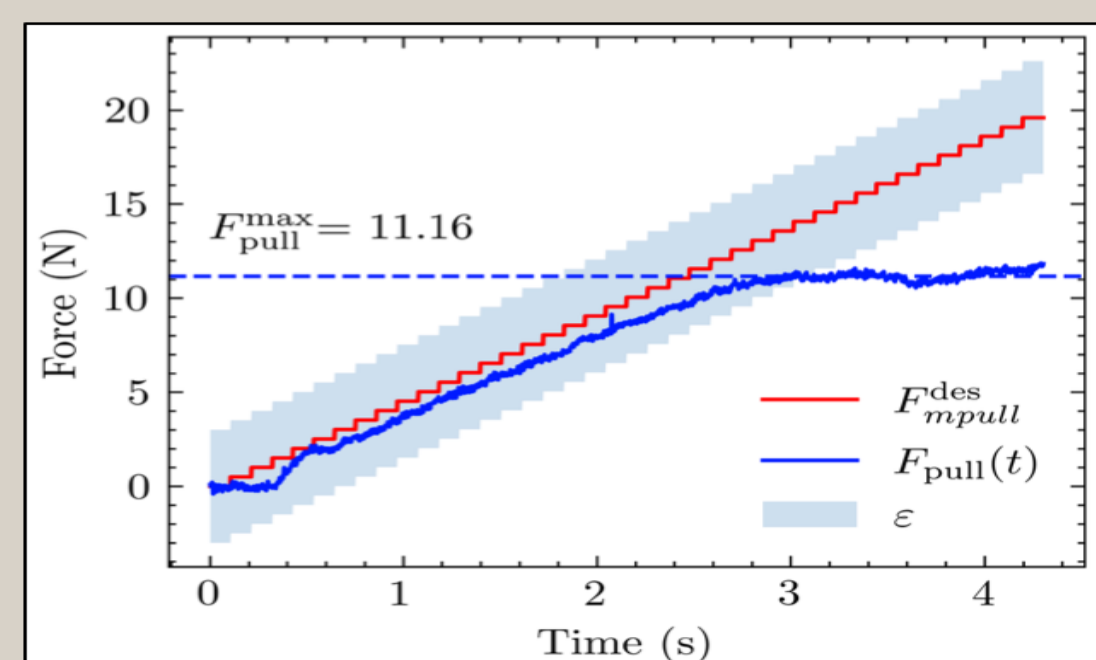## Digital Shadow of a Manufacturing System

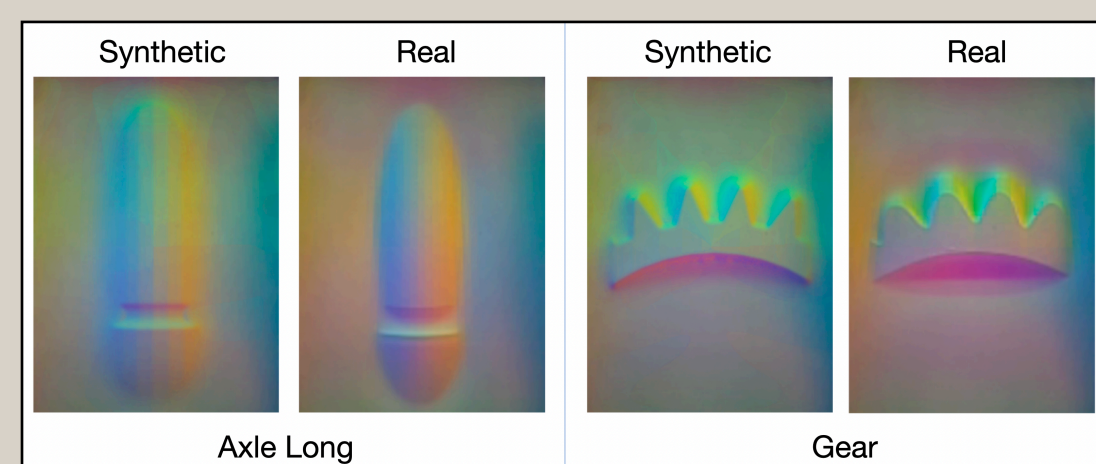THA Technische Hochschule Augsburg · TTZ Nördlingen Flexible Automation

(a) UR5 · WSG-50 Gripper · Gelsight R15 · Grasping Objects

Actual Physical System

Synthetic Camera RGB data · Synthetic Camera Depth data

Digital Shadow

$F_{pull}^{max} = 11.16$

$F_{mpull}^{des}$ · $F_{pull}(t)$ · $\varepsilon$

Force (N) vs Time (s)

Dynamics Prediction

Synthetic · Real · Synthetic · Real
Axle Long · Gear

Generation of Synthetic Data

Paper #1

Paper #2

## Other Collaborators and Partners

CATAPULT Digital · elite · IEEE Control Systems Society · NIACE Advanced Composites and Engineering · ARQ RELIABILITY · NEURAL ENGINEERING DATA CONSORTIUM · Northumbria University NEWCASTLE

## Selected Key Publications

- "Predicting Maximum Permitted Process Forces for Object Grasping and Manipulation Using a Deep Learning Regression Model," *IEEE CCTA*, 2024.
- "Learning to Predict Grip Quality from Simulation: Establishing a Digital Twin to Generate Simulated Data for a Grip Stability Metric," *arXiv preprint arXiv:2302.03504*, 2023.
- "A Realistic Simulation Testbed of a Turbocharged Spark-Ignited Engine System: A Platform for the Evaluation of Fault Diagnosis Algorithms and Strategies," *IEEE Control Systems Magazine*, 2020.
- "Design and Selection of Additional Residuals to Enhance Fault Isolation of a Turbocharged Spark Ignited Engine System," *IEEE CoDIT*, 2020.
- "Combining model-based diagnosis and data-driven anomaly classifiers for fault isolation," *Control Engineering Practice*, 2018.
- "Real-Time Closed-Loop Color Control of a Multi-Channel Luminaire Using Sensors Onboard a Mobile Device," *IEEE Access*, 2018.
- "A Sliding Mode Observer for Infinitely Unobservable Descriptor Systems," *IEEE Transactions on Automatic Control*, 2017.
- "Development of a prototype smart home intelligent lighting control architecture using sensors onboard a mobile computing system," *Energy and Buildings*, 2017.
- "A combined diagnosis system design using model-based and data-driven methods," *IEEE SysTol*, 2016.
- K. Y. Ng, "Design and Development of A Simulation Environment and A Fault Isolation Scheme on A Volvo VEP4 MP Engine," Research and Development Centre, Volvo Car Corporation, Gothenburg, Sweden, Tech. Rep., 2015.