Ultrafast laser damaging of ball bearings and anomaly detection for condition monitoring of fleet of linear motors

PhD Candidate : Abdul Jabbar

Supervised by : Marco Cocconcelli

Department of Engineering Sciences and Methods, University of Modena and Reggio Emilia (UNIMORE)

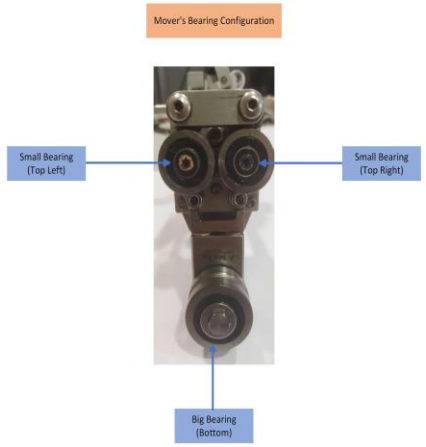
MSCA-ITN- Marie Sklodowska-Curie Innovative Training Networks (ITN)

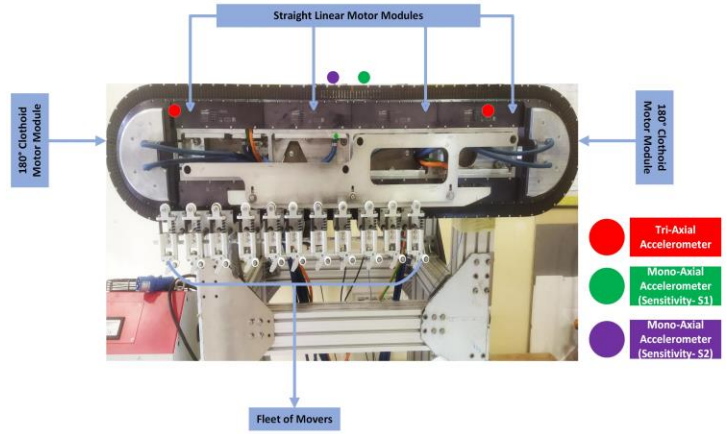
Monitoring of large scale complex technological systems (MOIRA)

Independent Cart System

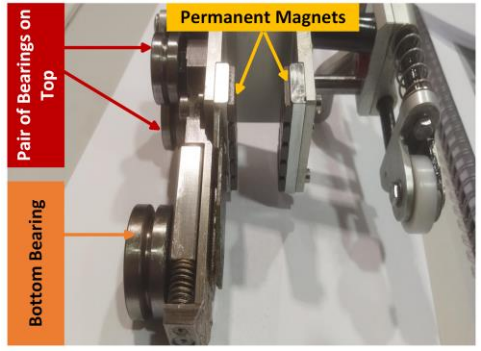
System is miniaturized version of an industrial packaging machine. Main Components include,

- Motors (Stator of Linear motor)
  - Linear motors with straight and curved stator geometry
  - Each motor is equipped is with a set of electromagnetic coils that generates changing magnetic field to facilitate motion of carts.
- Movers/Carts (Rotors of Linear motor)
  - Magnetically driven passive components.
  - Each mover contains a set of three bearings.
- Guide Rail
  - Installed parallelly behind the motor modules.
  - Allows carts to glide along the desired trajectory.
- Vibration Sensors
  - 5 vibration sensors (3 mono-axial, 2 tri-axial)
  - Vibration sensors are directly attached to the guide rail.
  - Sampling rate is 50kHz.



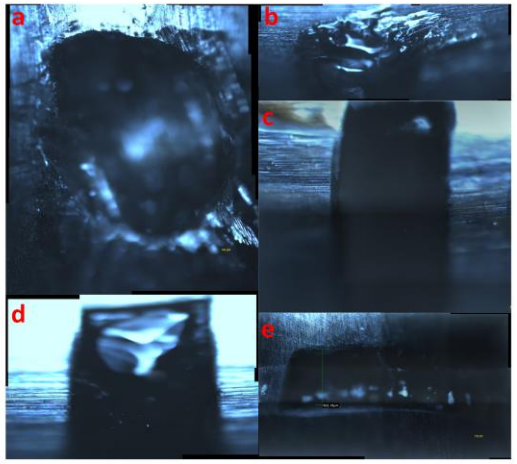


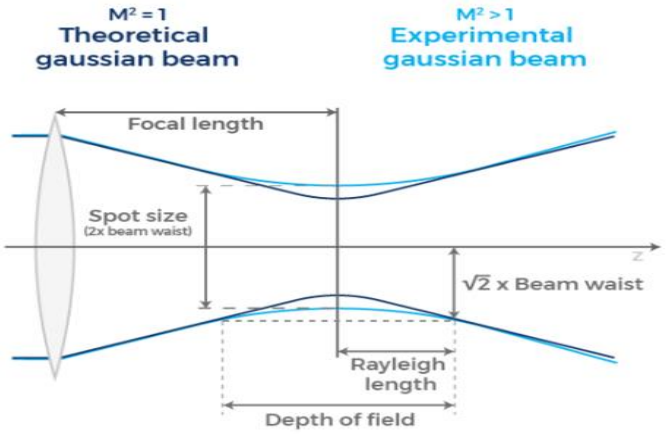
Cart Configuration

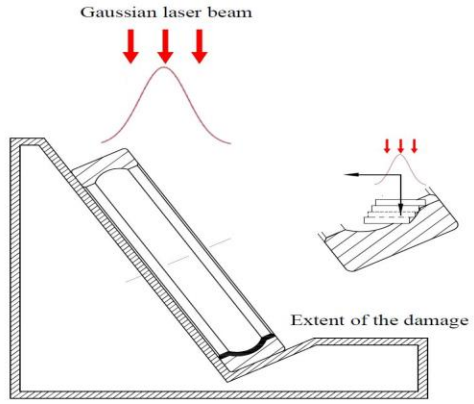


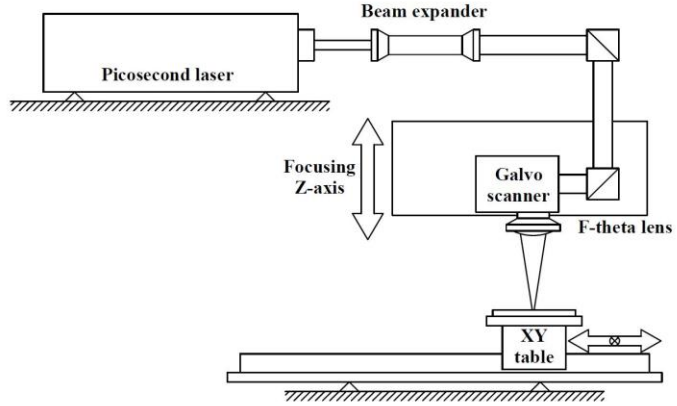
Bearing Fault Injection Campaigns

- Manual (Without Dismantling)
  - Faults were injected in the raceways using drill mils.
  - Imprecise dimensional control, due to proximity of inner and outer races along with rolling elements.
- Laser
  - Picosecond laser source
  - Generates Gaussian beam profile at the IR wavelength of 1064nm.
  - It produces ultrashort pulses in picoseconds regime.
  - No limitation in terms of hardness of the bearing material.









Problem Statement

To identify faults in the bearing and ultimately localize the faulty bearing in a fleet of moving carts.

Step 1:

Binary Classification:

- To classify the data with faulty bearing from the data with no-fault

Faulty identification:

- Identify the type of the fault
- Location of bearing (top or the bottom bearing)

Step 2:

Cart Localization

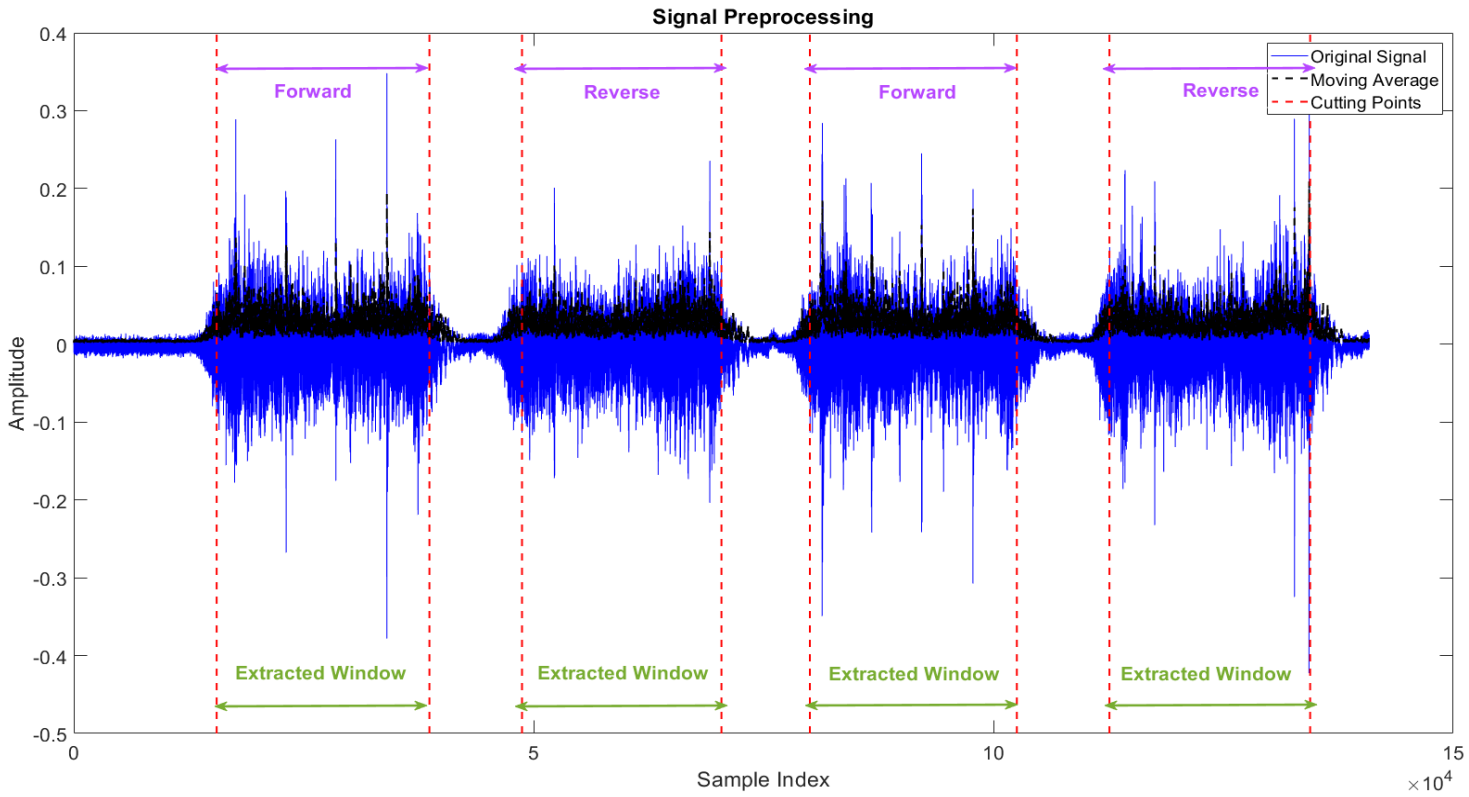
- Not only identify the type of the fault but also identify the specific “Cart” that is carrying the Faulty Bearing.
- Problem of fault localization becomes progressively challenging with,
  - the increase in number of movers, especially when the same machine on industrial scale has 100s of movers.
  - With the addition of every Mover/Cart the number of bearings increase by 3.
  - The spacing between two top bearings is approximately 1.3mm

Data Preprocessing

Experiments were conducted single mover moving back and forth at 1m/s.

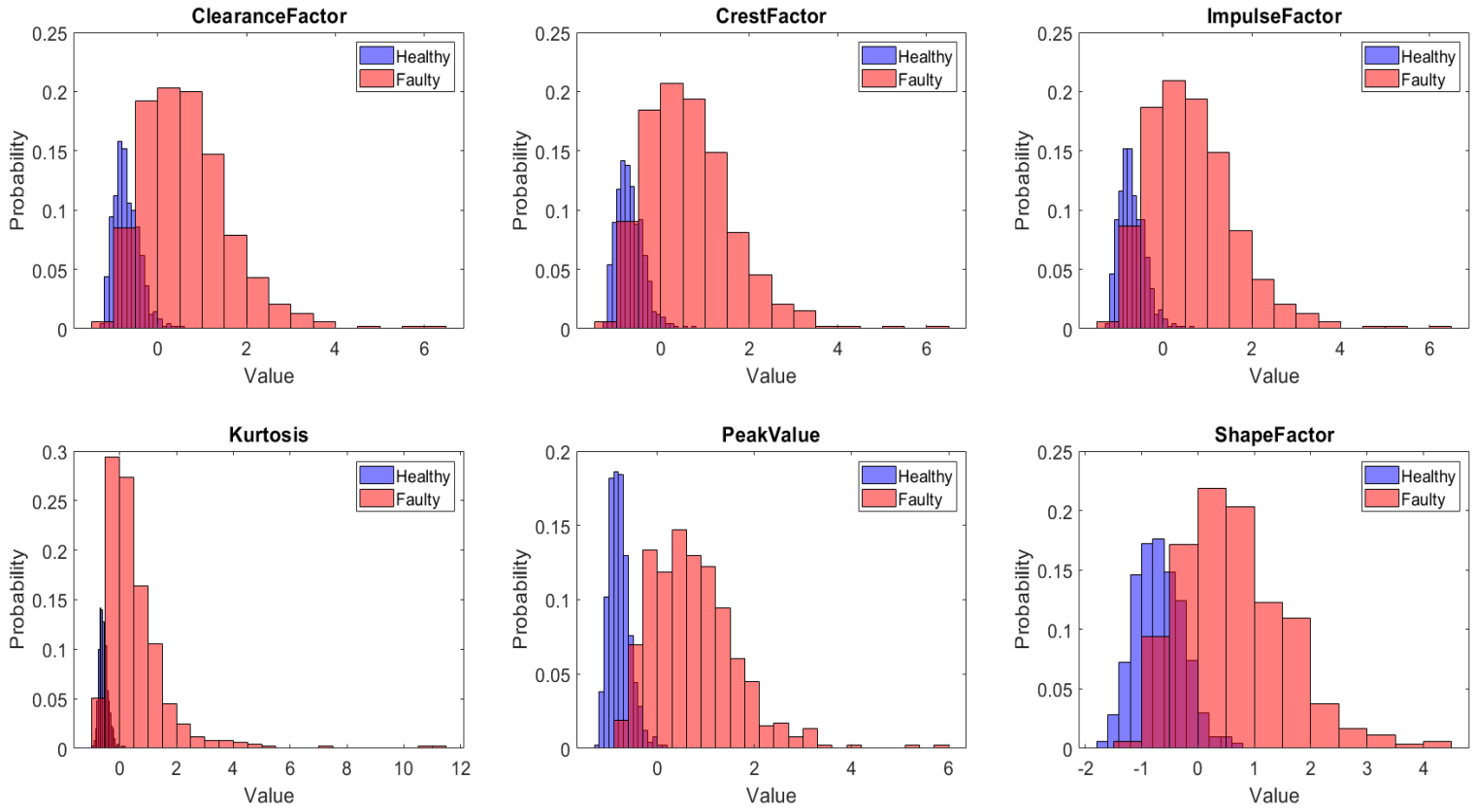
Since it's a back-and-forth motion, mover's speed also fluctuates between 0 and 1 m/s.

Moving average based filter, extracts the windows to remove data during speed fluctuations.

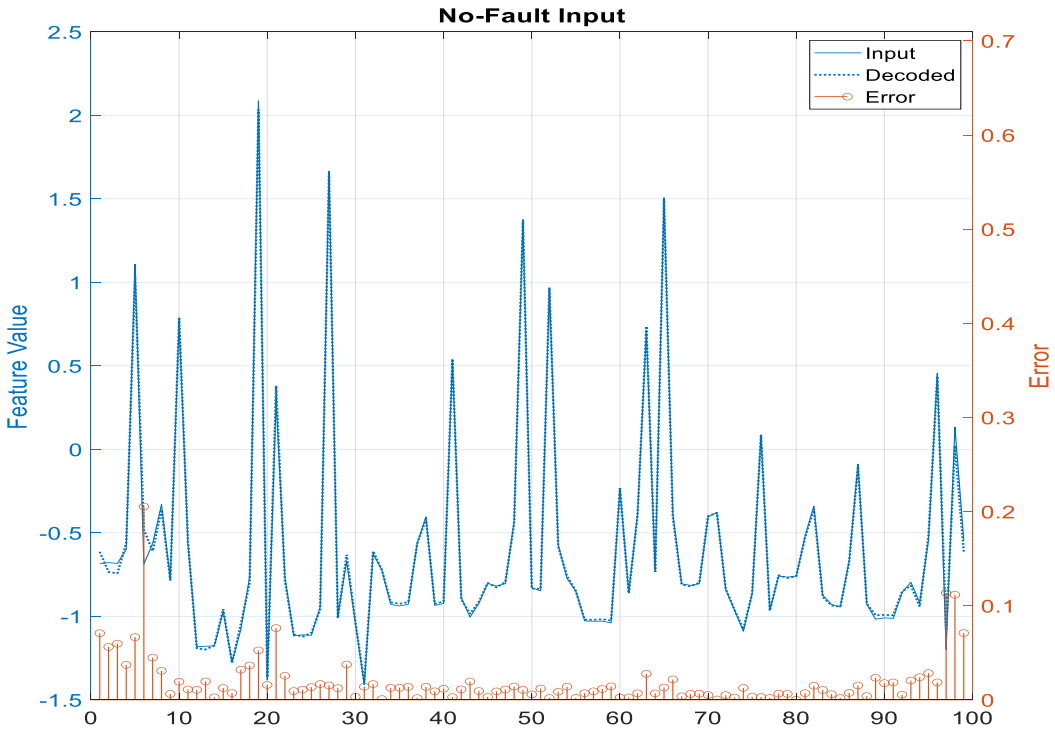


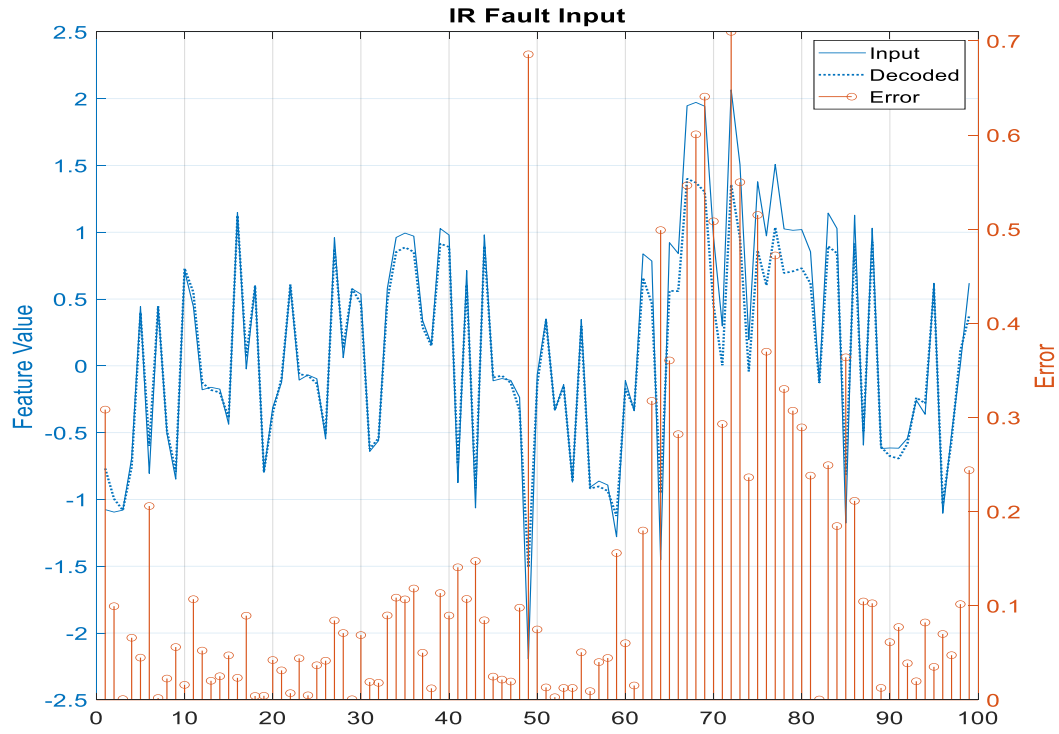
Time Domain Statistical Features

Statistical Feature Set	
RMS	$x_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\lvert x_i\rvert^2}$
Standard deviation	$x_{std} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\lvert x_i - \mu\rvert^2}$
Shape factor	$x_{shape} = \frac{x_{rms}}{\frac{1}{N}\sum_{i=1}^{N}\lvert x_i\rvert}$
Kurtosis	$x_{kurt} = \frac{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^4}{\left[\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2\right]^2}$
Skewness	$x_{skew} = \frac{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^3}{\left[\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2\right]^{3/2}}$
Peak value	$x_p = \max_i \lvert x_i\rvert$
Impulse Factor	$x_{IF} = \frac{x_p}{\frac{1}{N}\sum_{i=1}^{N}\lvert x_i\rvert}$
Crest Factor	$x_{crest} = \frac{x_p}{\sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2}}$
Clearance Factor	$x_{clear} = \frac{x_p}{\left(\frac{1}{N}\sum_{i=1}^{N}\sqrt{\lvert x_i\rvert}\right)^2}$

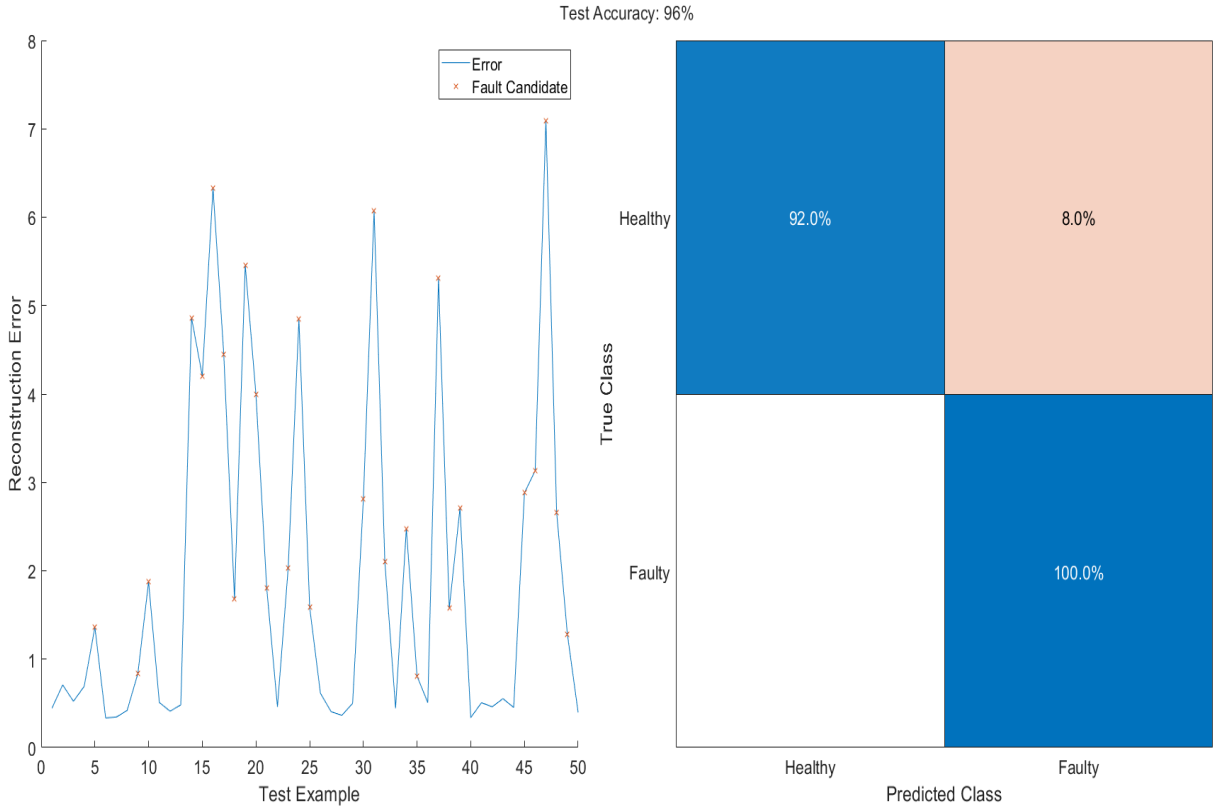


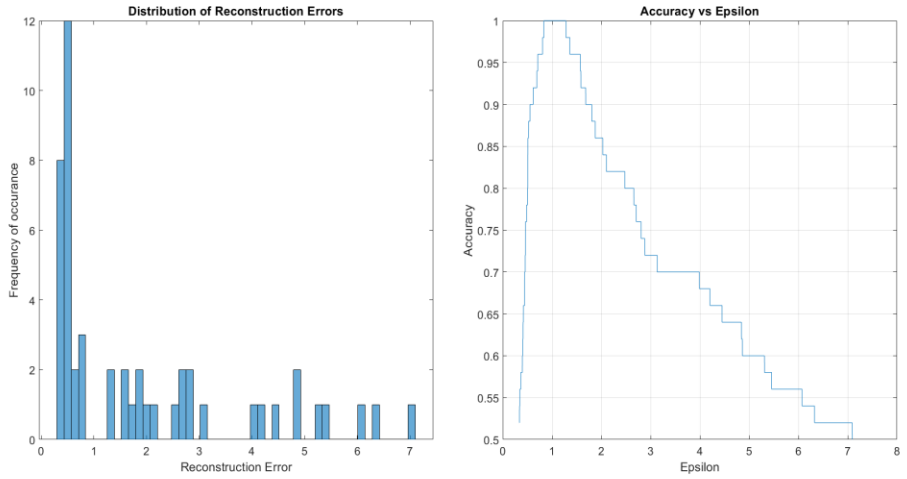
Anomaly Detection (Results and Discussion)

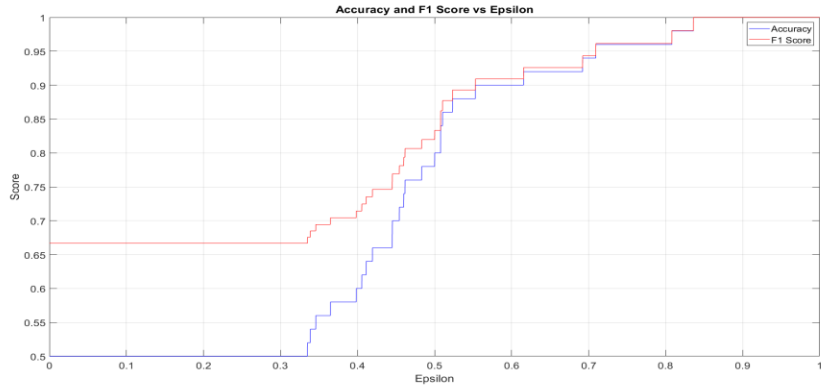




Results and Discussion







UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

UNIVERSITAS STUDIORUM MUTINENSIS ET REGIENSIS 1175

PROTECTS WHAT'S GOOD Tetra Pak®

MSCA-ITN- Marie Sklodowska-Curie Innovative Training Networks (ITN)

Monitoring of large scale complex technological systems (MOIRA)

Acknowledgements

This work has received funding from European Commission through the Marie Sklowdoska Curie ETN MOIRA project (GA 955681)