Structural Analysis of Mechanical Defect in Solid Propellant Grain Using Machine Vision & Artificial Intelligence

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Sandip Suman, PhD (Principal Engineer)
Date: 7/12/2024

PRESENTER BIO

- Sandip Suman has been working as a Principal Engineer at the Ejection & Propulsion division of Collins Aerospace (A Raytheon Company) for the last seven years. He has a PhD in Mechanical Engineering with around 25 years (academia & industry combined) of engineering experience.
- Prior to Collins, Dr. Suman worked in the automotive industry for 7 years, and in academia (KU & NDSU) for almost a decade as a faculty and researcher.
- Dr. Suman is a well-known international expert in Multiaxial Fatigue & Fracture. He has also done research in the structural application of artificial intelligence & pattern recognition technology. His artificial intelligence-based pattern recognition work has also been listed by Smithsonian. He has several conference proceedings, journal papers, and book chapter publications (Mechanical Fatigue of Metals, Springer publication). He is also the creator of the famous SK Critical Plane Method for Multiaxial Fatigue.
- He has given talks at several national and international conferences and has served on International Conference on Multiaxial Fatigue and Fracture and ASTM E08 committees. He also won the Best Research Presentation Award at NDSU.
- Currently, Dr. Suman has been leading research on AI-based Defect Detection Technology for rocket motor grains at the Fairfield, CA site of Collins, and here to present his work.

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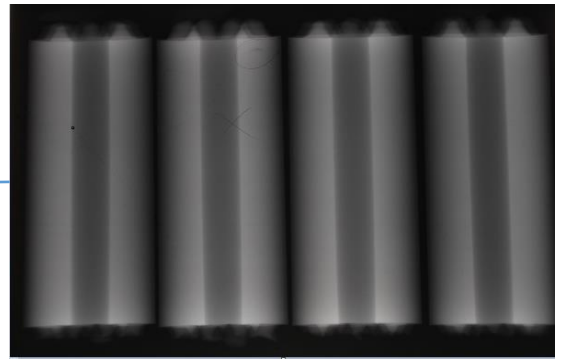
OVERVIEW & OBJECTIVE

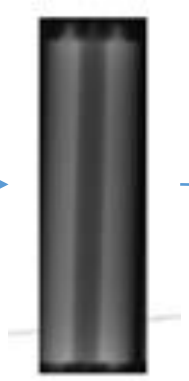
- Develop AI based image processing algorithm for the detection of cracks, voids and foreign materials in energetic assemblies
- Develop concept model to demonstrate the basic functionality of technology
- To improve accuracy, efficiency, customization and scalability
- Automation with human like intelligence
- Enhance the productivity and minimization of production downtime
- Minimize variability and improve consistency in analysis and process

WHAT IS AI/MACHINE VISION



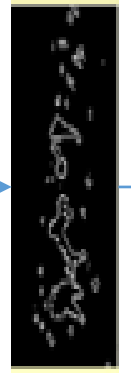
Raw x-ray

Camera/ Digitizer



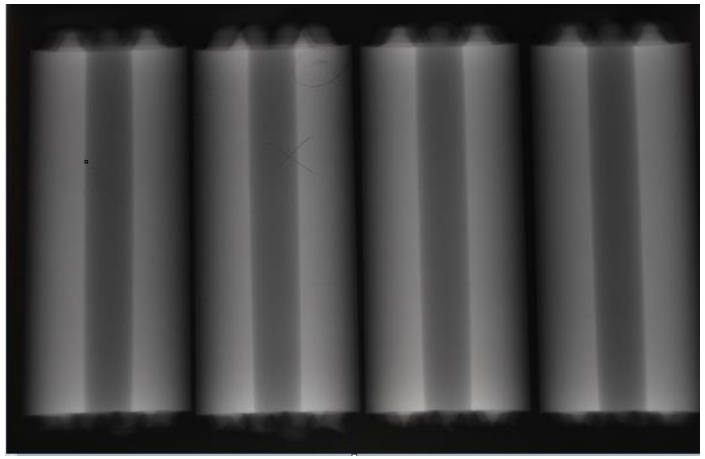
Digitized

Computer



AI Tool

CURRENT PROCESS & LIMITATION



Inspector
???????

1. Hard to detect
2. Experience of examiner
3. Consistencies
4. No analytical correlation
5. Human Fatigue

- Slow & Tedious Process
- Poor customer satisfactions
- Delivery delay
- Reduced Risk

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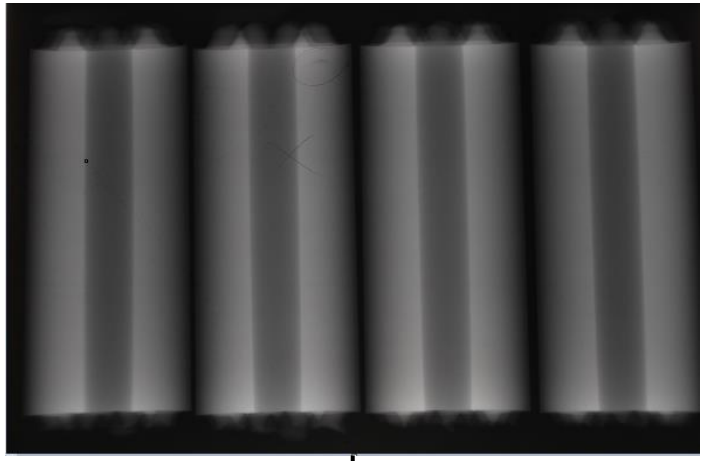
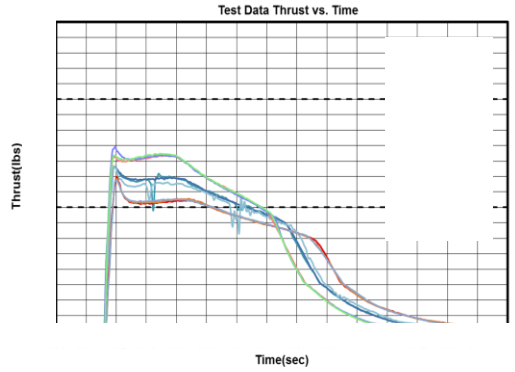
PROPOSED SOLUTION

- Uses **Hardware** and **Software** in combination
- Use of historical data for training of AI-Neural Network
- Pattern recognition of defects
- Connect Defect and performance parameters
- Optimize Performance by proposing controlled process parameters



AI-Defect Detection (AIDD)



VALUE PROPOSITION

Current State (Manual inspection)	Future state (AIDD System)
Induced human fatigue	Focused human decision making
Accuracy (Highly human dependent)	Optimized human involvement
Long cycle time	Focused value-added tasks
Reliability	AIDD assisted human decision (Improved)
Manual inspection	AIDD System
Operator based knowledge	Sustainable system knowledge
Constrained capacity	Flexible capacity (data driven management)

IMAGE ACQUISITION

- Digital image with known PPI & x-ray Parameters
  - camera
  - digital scanner
  - digital x-ray machine
- Known lighting parameter
- Clear information about background color
- Camera parameter if any

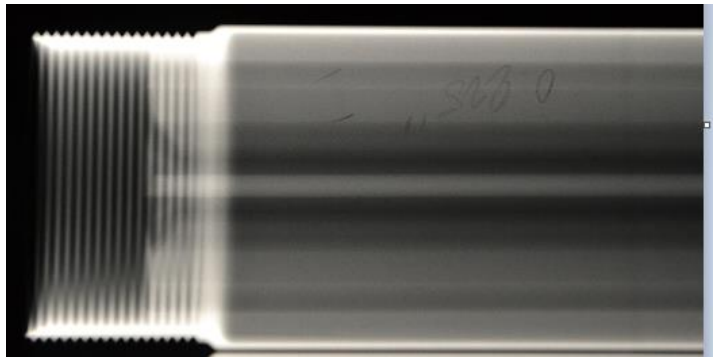


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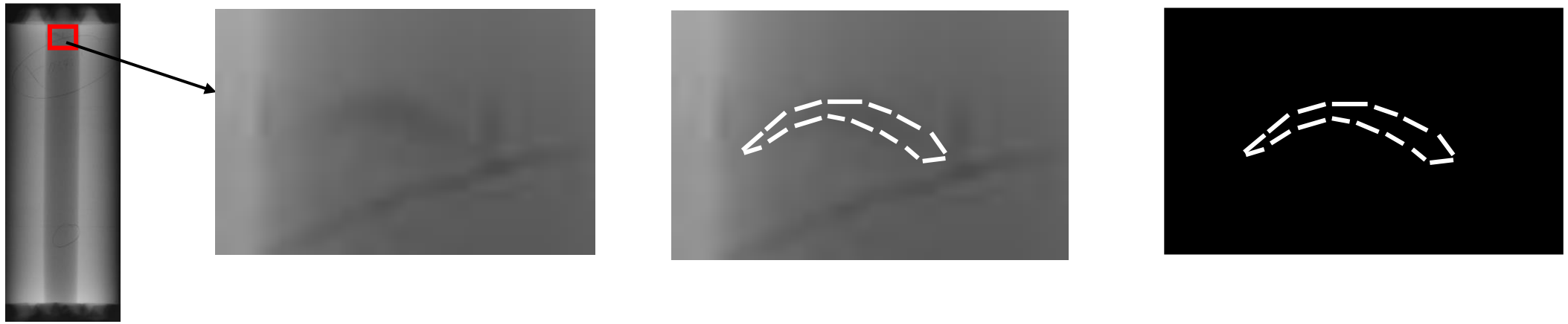
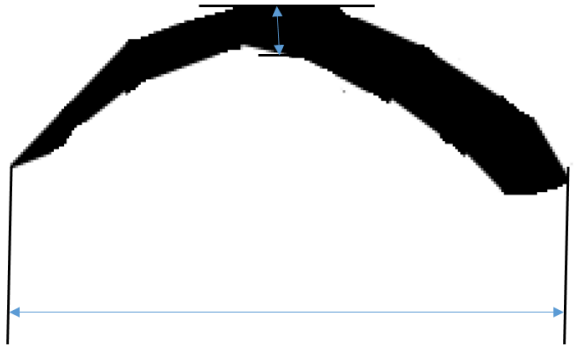
IMAGE PROCESSING

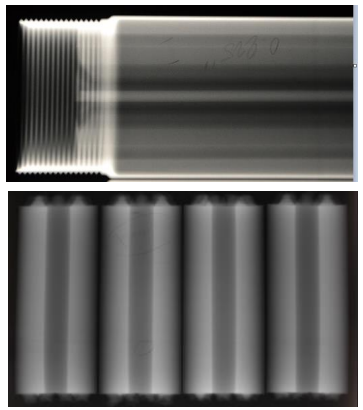




DEFECT PARAMETERS

- Length of crack
- Width of crack
- Some of the sharp angles of different locations
- Over all area of the defect

MACHINE VISION & AI



Radiography of Rocket Motor/GG

Digitization of Radiographs/Mechanical Defects

Feature Extraction

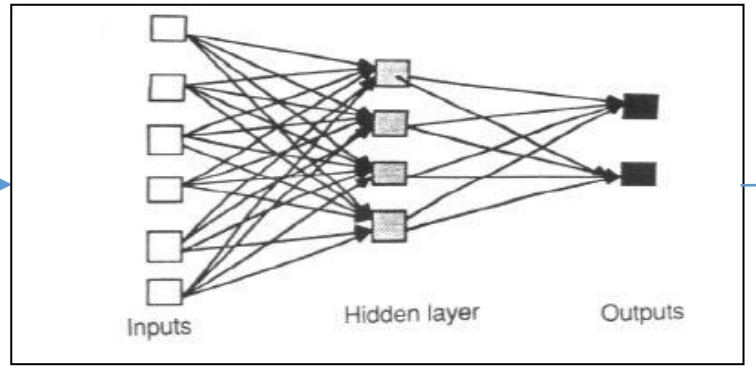
Measurement of features

Mathematical Modeling of Features

Pattern Recognition

Characterization of Defects/Damage Analysis and Performance Estimation

Training Data/Old Digital Radiographs



Training of Neural Network

CUSTOMER REQUIREMENT

Pictures are not related, and has only shown here to explain the concept

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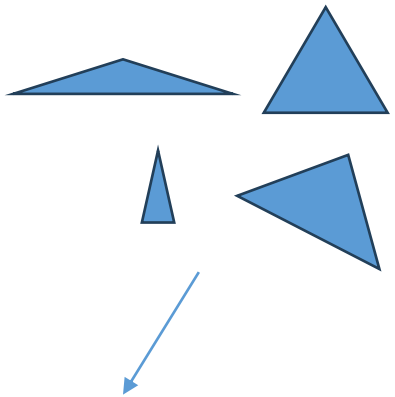
BUILDING OF AI NEURAL NETWORK

Artificial Defect Based Approach

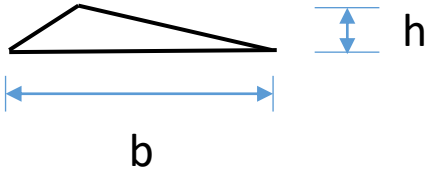
- Defects are created manually to introduce in the image for training purpose
- Complement contrast (reverse contrast to make crack and defects more visible)
- Reconstruction based methods: Self trained encoders and decoders to reconstruct the images for anomaly detection

BUILDING OF AI NEURAL NETWORK

Geometrical Shape Based Approach



Human Learning



BUILDING OF AI NEURAL NETWORK

Geometrical Shape Based Approach

Generate circle

Generate Ellipse

Generate Square

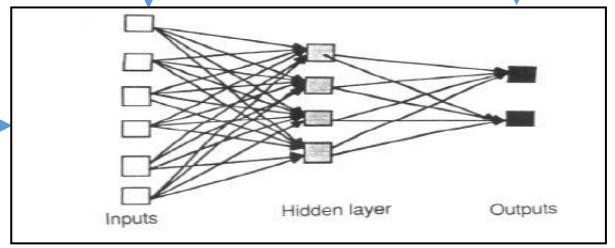
Generate Triangle

AI-Defect Detection System (AIDD)

Input matrix

Target matrix

Neural Network Training



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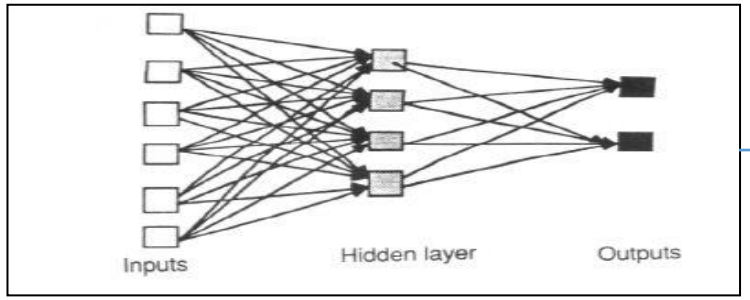
ANALYSIS PROCEDURE

Acquire Digital Image

AI-Defect Detection System (AIDD)



Defect Classification

Measure parameters (Length, Width, Area)

Drawing Requirement

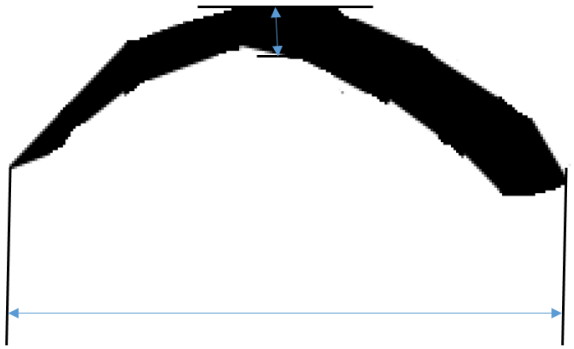
Accept/Reject

Yes

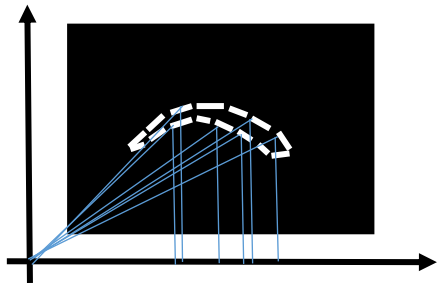
NO

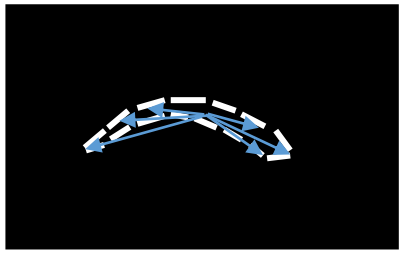
DEFECT ANALYSIS

Measurement of features

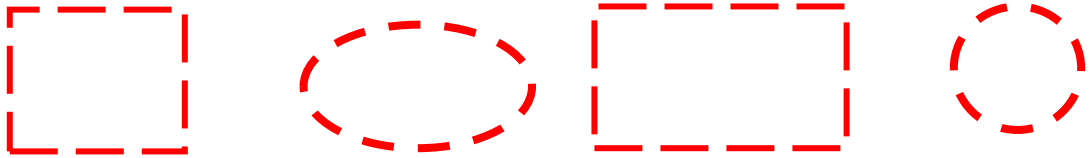


Mathematical Modeling of Features



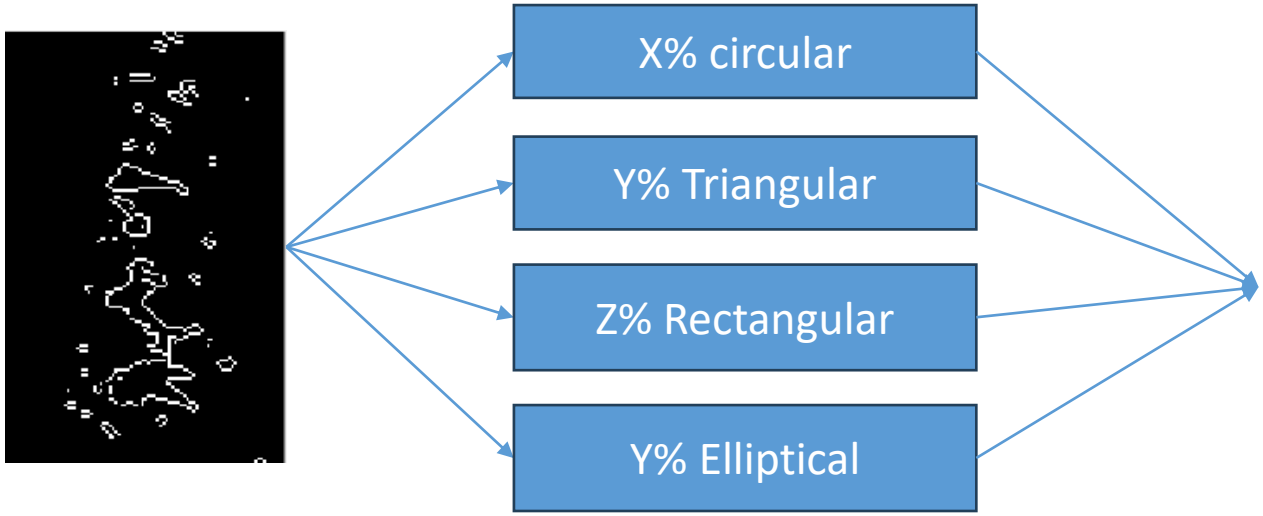


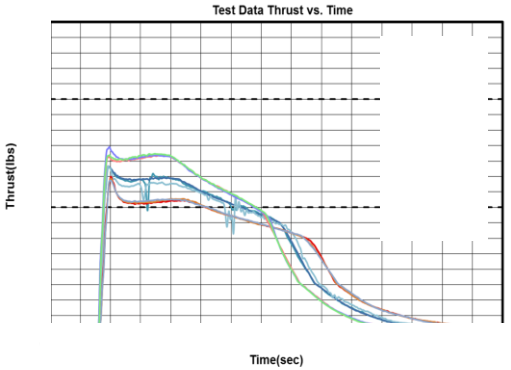
Rectangular to Polar Coordinates



PATTERN & PERFORMANCE

- Understand the shape of the defects
- Mathematically model the defect
- Analyze the defect for its burn pattern
- Predict the ballistic performance curve





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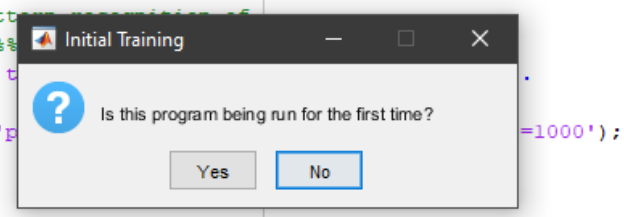
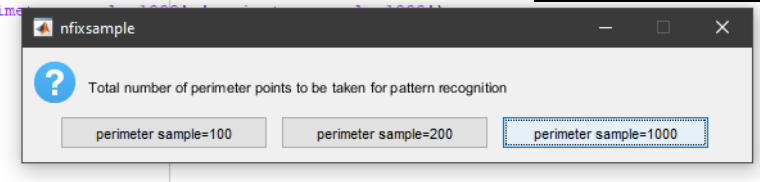
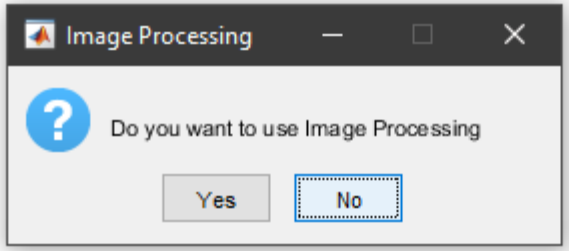
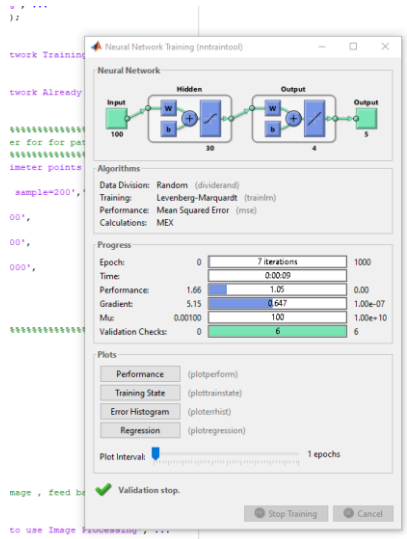
PROOF OF CONCEPT

Input image









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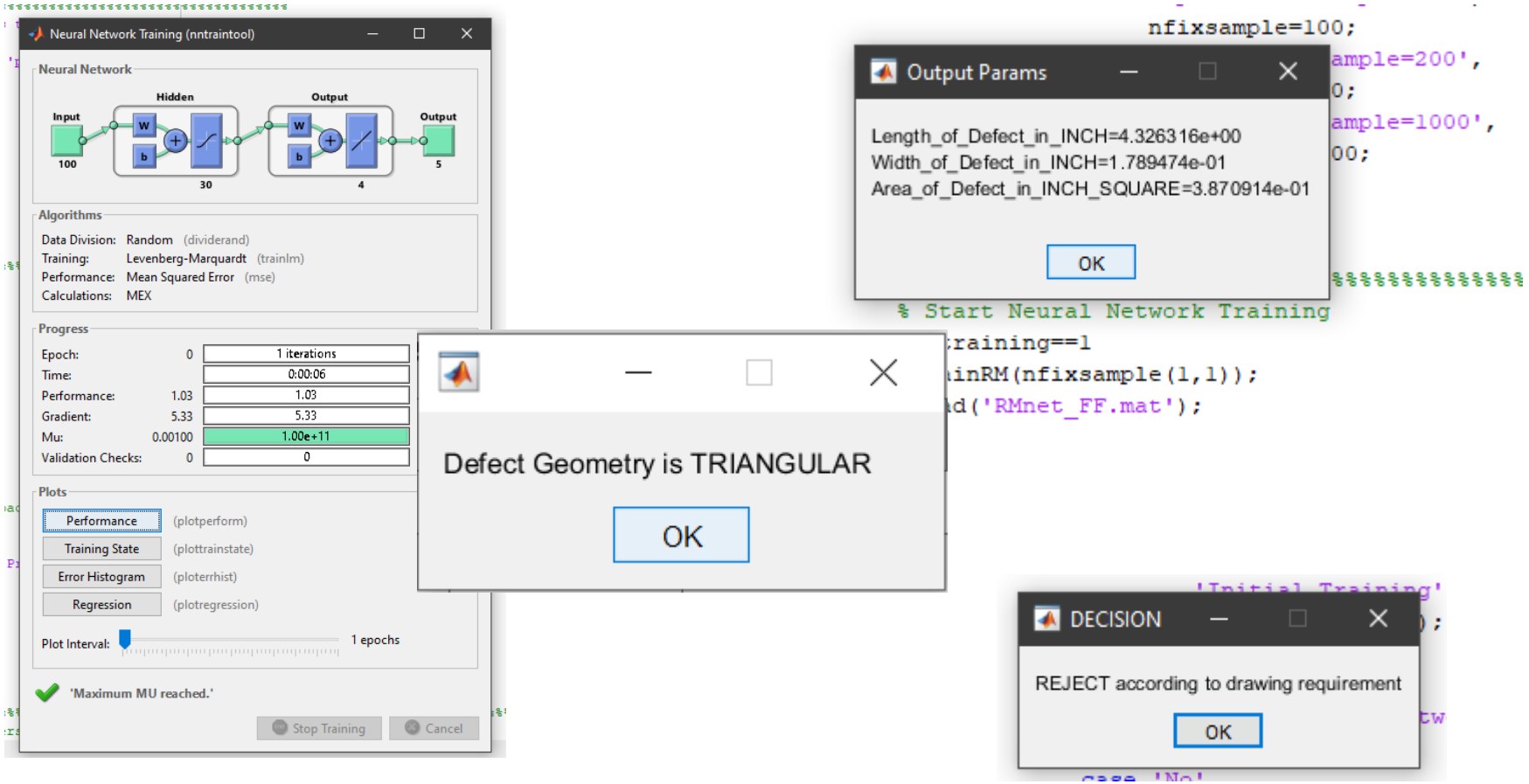
SAMPLE OUTPUT



COLLABORATION

- RTRC
- ATC
- Others??????

ACKNOWLEDGEMENT

- My Leadership
- Engineering Team at Fairfield
- Conference Committee

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THANK YOU FOR YOUR ATTENTION AND ATTENDANCE

Questions?????

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