A Fuzzy Expert System for C/C Composite Aircraft Brake Disks by Using ACUT

Yicheng Peter Pan, Tsuchin Philip Chu
Department of Mechanical Engineering and Energy Processes, Southern Illinois University, Carbondale, Illinois 62901

INTRODUCTION

- Fuzzy expert system technique was used to identify defects in commercial Carbon-Carbon (C/C) composite aircraft brake disks by using air-coupled ultrasonic Testing (ACUT).
- Data features and NDE expert knowledge were seamlessly combined in the intelligent system to provide the best possible diagnosis of the potential defects and problems.
- The model successfully classified and indicated the defect's size and distribution.
- As a result, this research work helped to determine C/C composites' integrity and reliability.

The Basic Building Block of an ACUT Fuzzy Expert System

1. **Specify the problem and define linguistic variables**

   Based on the signal amplitude of ACUT C-scan image, indentify the defect area

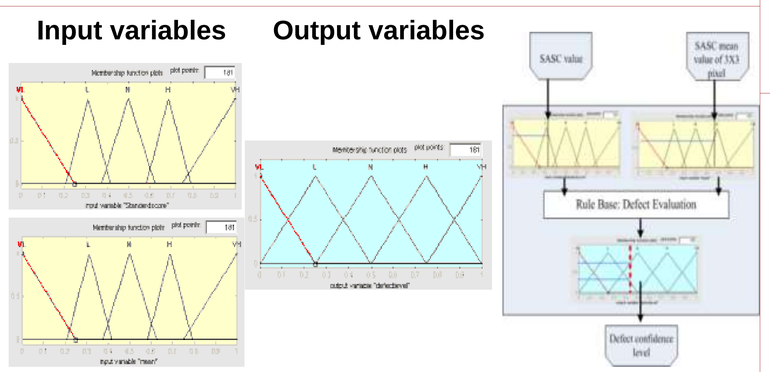
   - **Input variables: 2 input variables (0-1)**
     1. signal amplitude normalized in standard score of a pixel
     2. the mean value of signal amplitude normalized in standard score in 3x3 window of pixel.

     very low (VL), low (L), medium (M), high (H), very high (VH)
   - **Output variables: defect confidence level (0-1)**

     very low (VL), low (L), medium (M), high (H), very high (VH)

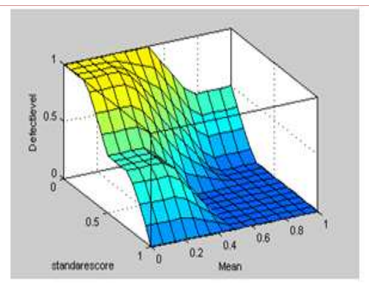
2. **Determine fuzzy sets**

   First, two inputs and one output variables are modeled by fuzzy sets in their respective domains



3. **Elicit and construct fuzzy rules**

   e.g. If standard score level is VL and mean density level is VL then defect confidence level is very high



Standard score \ Mean	VL	L	N	H	VH
VL	VH	VH	H	M	M
L	VH	H	M	M	L
N	H	M	M	L	VL
H	M	M	L	VL	VL
VH	M	L	VL	VL	VL

4. **Encode the fuzzy sets, fuzzy rules and procedures to perform fuzzy inference into the expert system**

5. **Evaluate and tune the system**

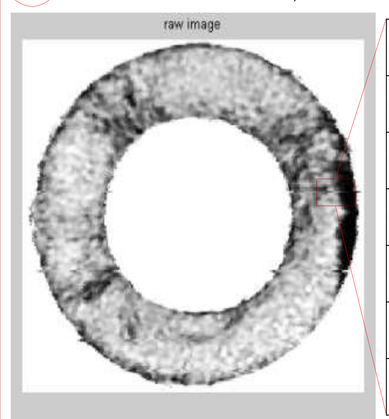
ENGINEERING APPROACH

After ACUT NDE inspection, ACUT C-scan signal amplitude images are processed by the fuzzy expert system, which is implemented in MATLAB. The fuzzy expert system imports C-scan images into a MATLAB file as an array of ACUT image, processes and analyzes the ACUT image data to a qualitative visualization of defects, employs the FISs and combines their results in order to draw the final conclusions.

Examples

Example 1: MABS HT C/C Disk

1 → **Data normalized in standard score** → **Each pixel has 2 input variables**



0.75	0.83	0.74	0.73	0.71	0.11	0.12	0.12
0.84	0.7	0.86	0.26	0.11	0.12	0.11	0.11
0.76	0.9	0.83	0.19	0.12	0.12	0.17	0.12
0.91	0.75	0.81	0.21	0.12	0.12	0.1	0.12
0.78	0.81	0.85	0.5	0.21	0.13	0.14	0.11
0.74	0.84	0.76	0.43	0.31	0.16	0.19	0.17
0.82	0.67	0.84	0.55	0.21	0.17	0.12	0.16

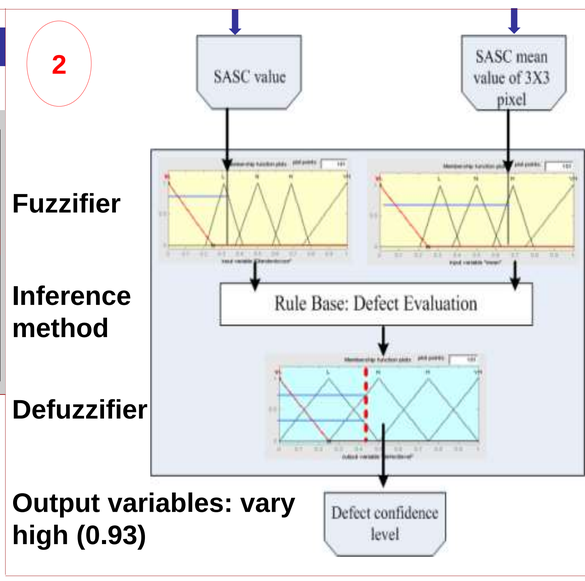
- **Input variables: 2 input variables (0-1)**
  1. Signal amplitude normalized in standard score of a pixel
  2. Mean value of signal amplitude normalized in standard score in 3x3 window of pixel.

  Very low (VL), low (L), medium (M), high (H), very high (VH)
- **Output variable: defect confidence level (0-1)**

  Very low (VL), low (L), medium (M), high (H), very high (VH)

Using Pixel number (5,3) as a example
IV1:0.12 **IV2:0.152**

2



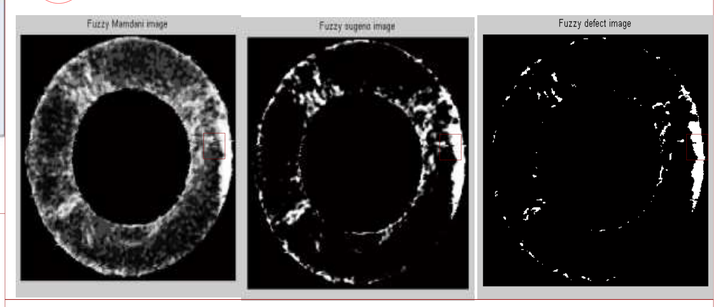
Fuzzifier

Inference method

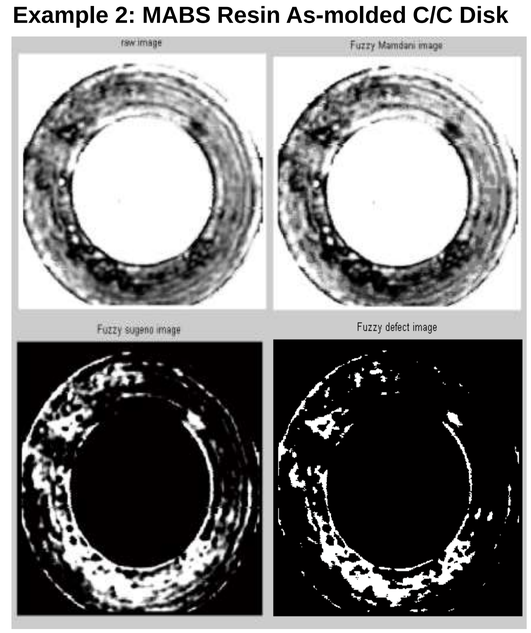
Defuzzifier

Output variables: vary high (0.93)

3 **Fuzzy expert defects detection output**



Example 2: MABS Resin As-molded C/C Disk



CONCLUSIONS

- Fuzzy Expert system provided plausible results for detecting the porosity location and distribution within the C/C disks and its results matches well with ACUT results.
- Function as an NDE expert and eliminates human error for defect detection.
- Improved the defect detection by incorporating fuzzy expert rules for better measuring defect and removing noise.
- Better compared to traditional NDE and weight measurement quality control methods.

ACKNOWLEDGEMENT

- **AIRSTAR INC., Irvine, CA**
  For letting us use their turnkey ACUT system for preliminary testing and providing us single channel ACUT instruments.

SOUTHERN ILLINOIS UNIVERSITY CARBONDALE

Intelligent Measurement & Evaluation Lab