The Fifth Annual Workshop for

Australian Network of Structural Health Monitoring

# Research Progress on Structural Damage Identification in Deakin University


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# Contents

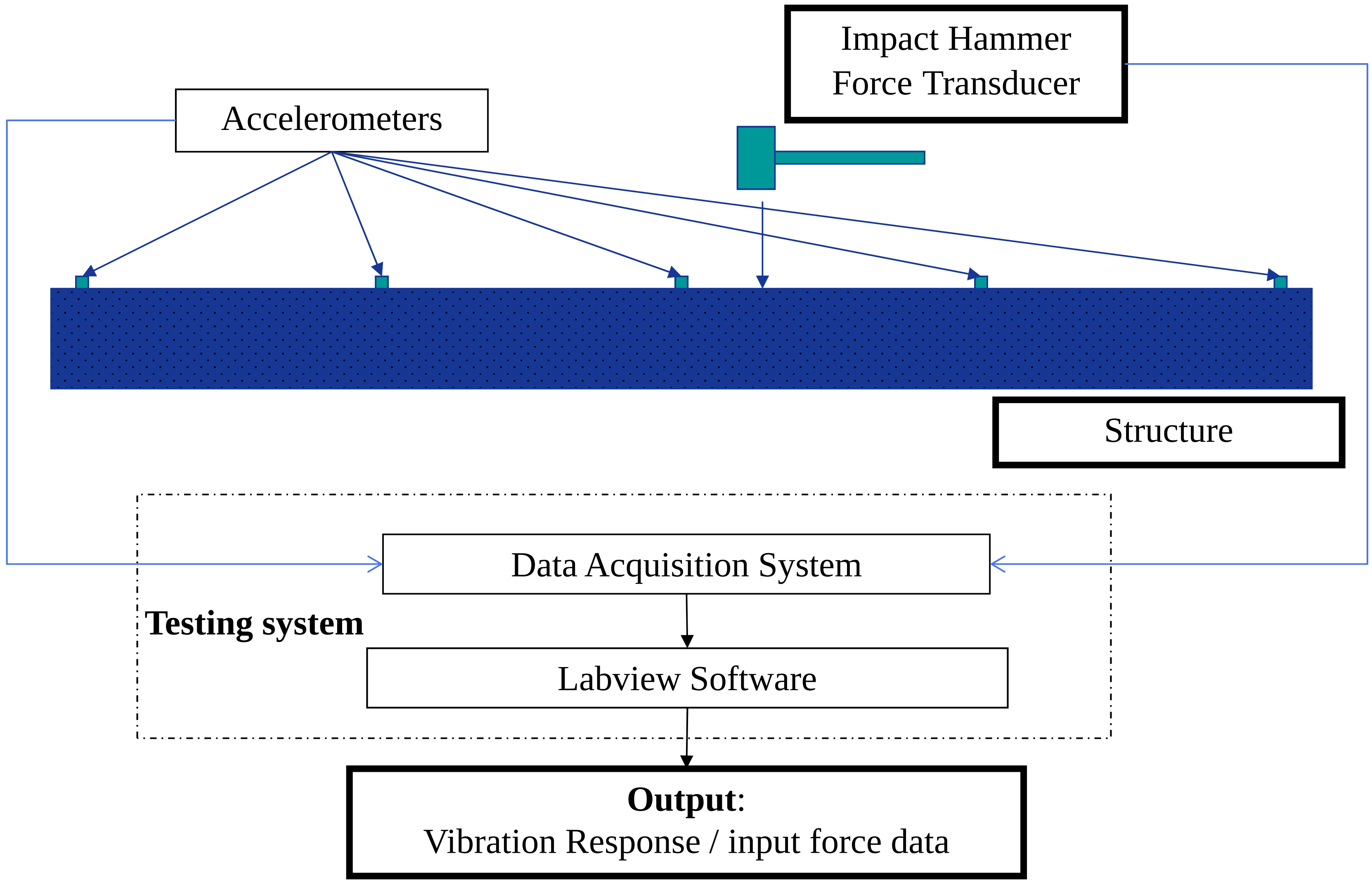
# Introduction

- Current SHM research has evolved to a new stage at which it is ready for practical application.
  - International perspective
    - Projects
    - Standards
  - Contribution from Australia

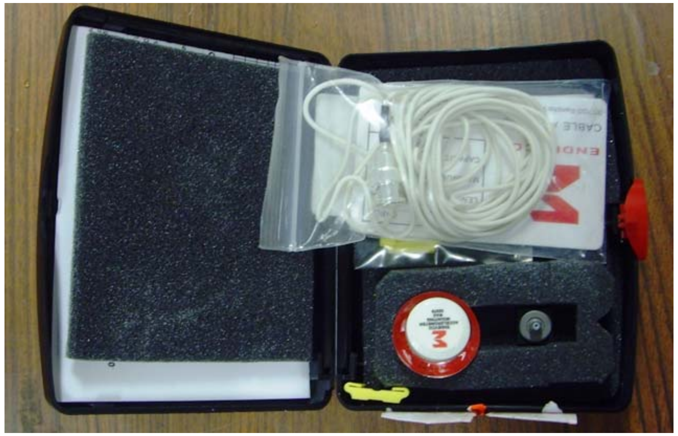
# Introduction

- In Deakin University, a research team on SHM led by Dr Ying Wang has been built since 2010, including 3 academic staff, 1 external academic staff, 1 PhD candidate, and a number of project students.
- Testing facilities include:
  - Vibration testing system
  - Guided wave test system
  - Bolt connected steel frame (as test specimen)
  - Pipe-soil interaction testing facility

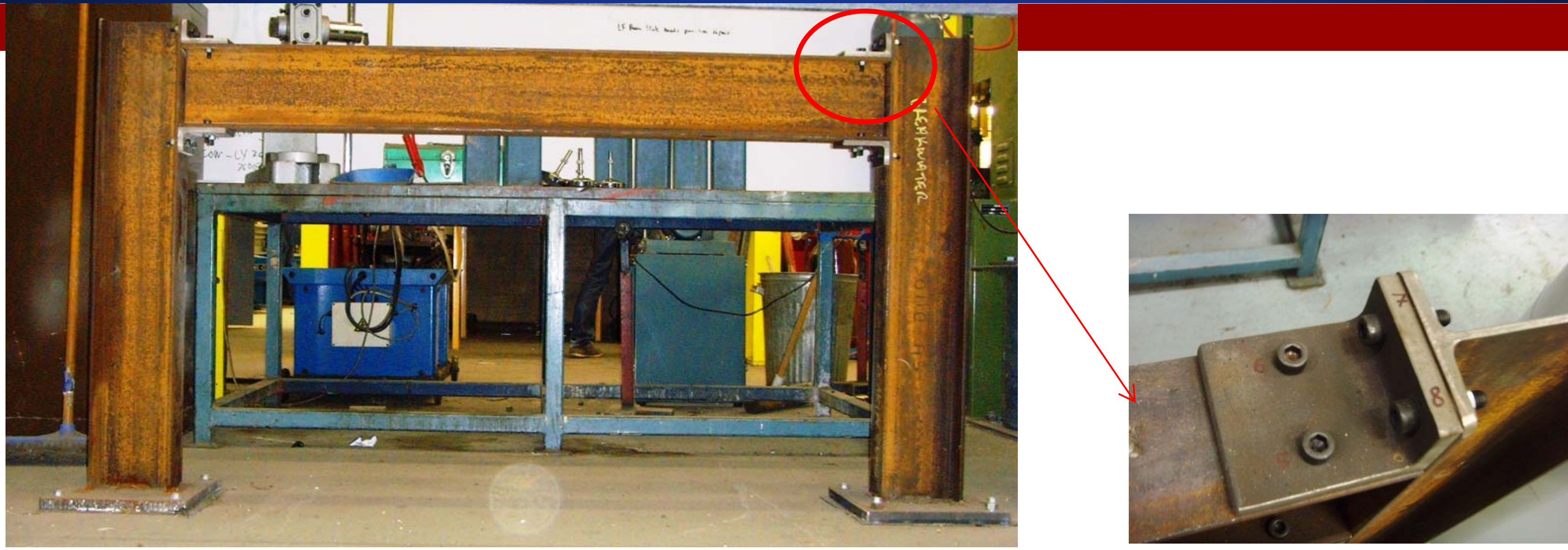
# Vibration Test Scheme



# Up-to-date vibration test system



# Testing facilities



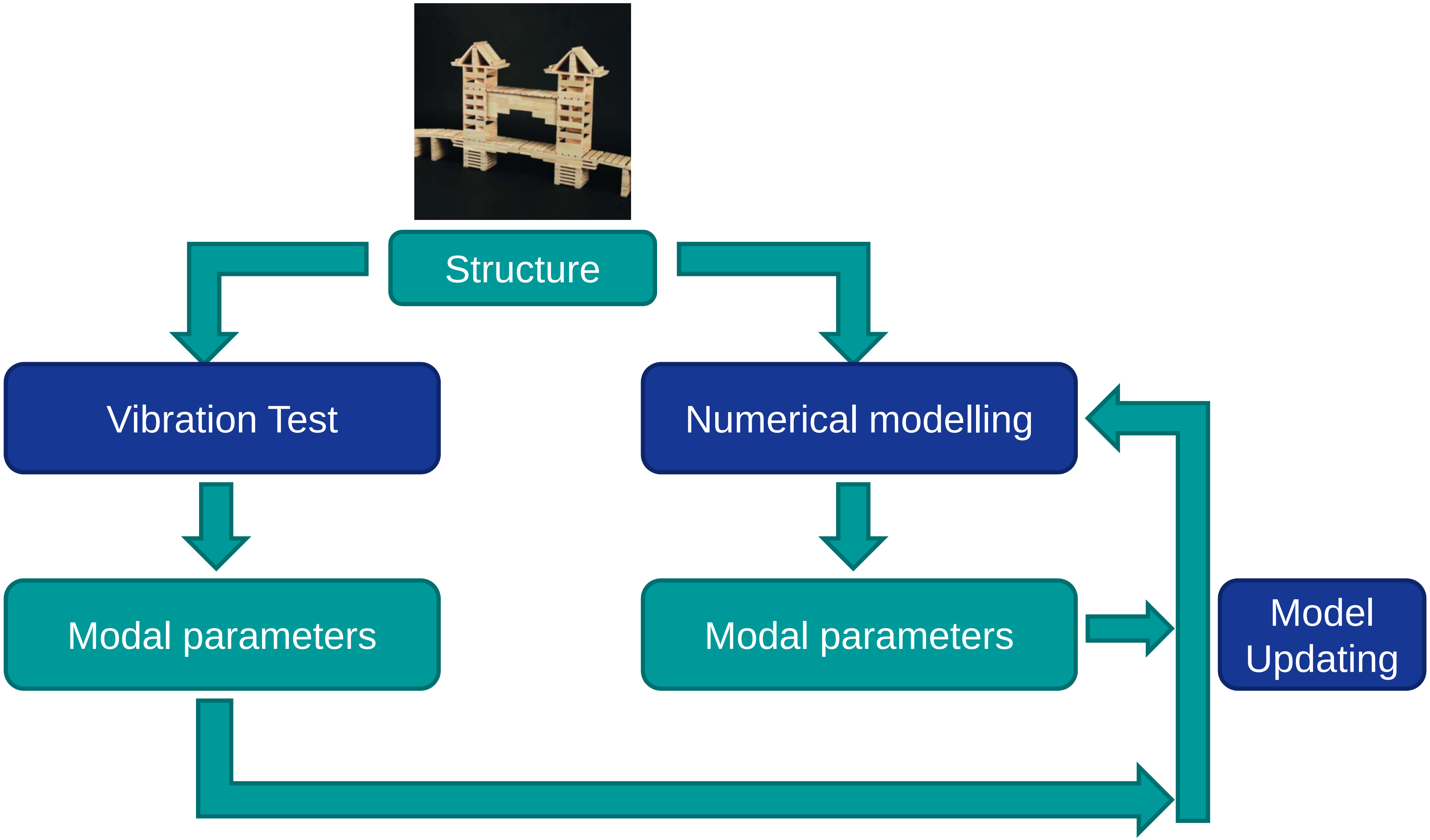
# Introduction

- Three viable approaches to vibration based damage identification have been proposed and developed

  - Damage identification via model updating
  - Damage identification via pattern recognition
  - Time series model for SHM

# Approach 1

- Damage identification via model updating



# Damage identification via model updating

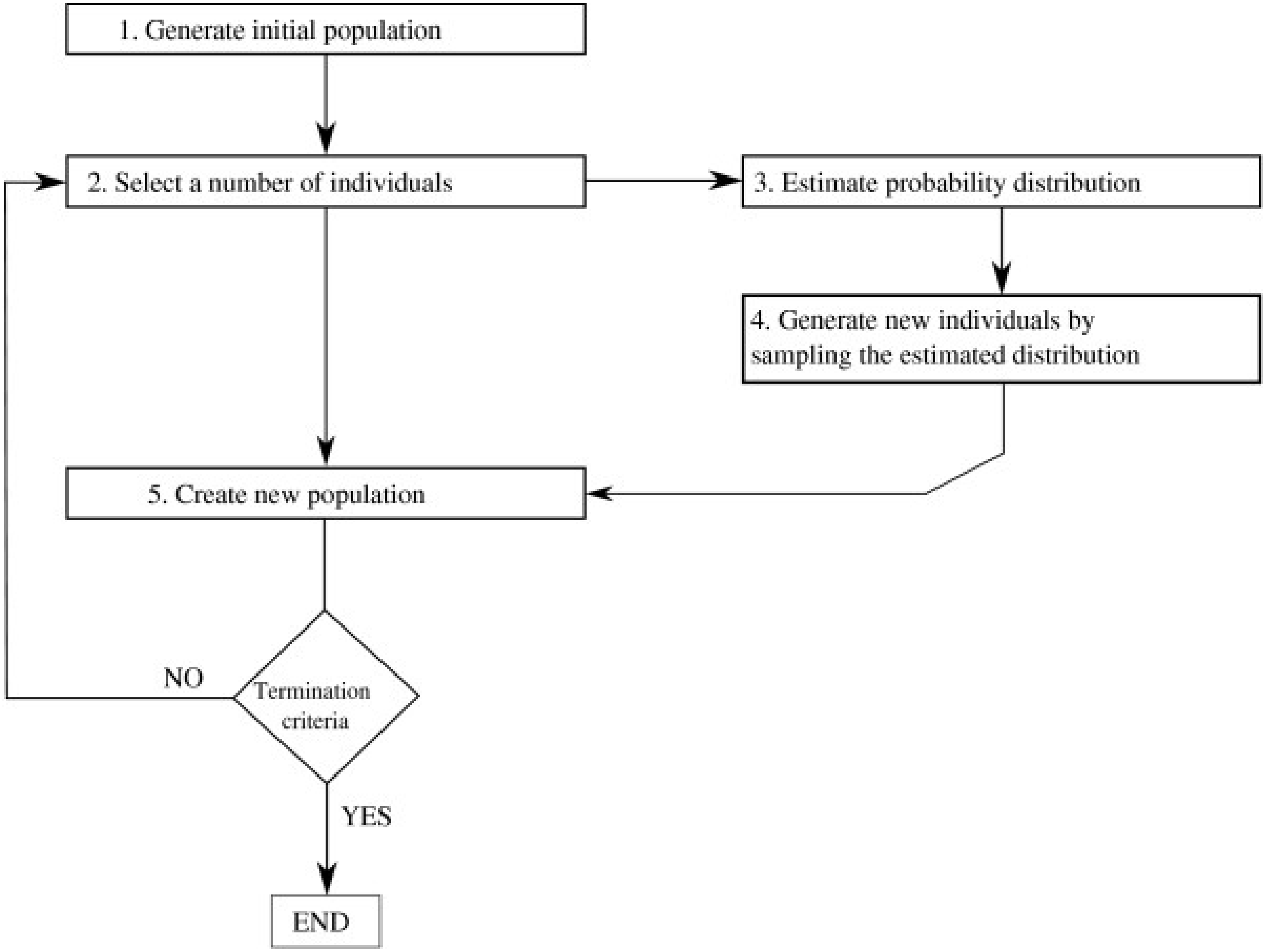
- In Deakin, Estimation of Distribution Algorithms have been investigated as the optimization algorithm.

  - While the genetic operators used by GAs may have a disruptive effect on problems with complex interactions, EDAs overcome this drawback by capturing and using the interactions to generate new solutions.

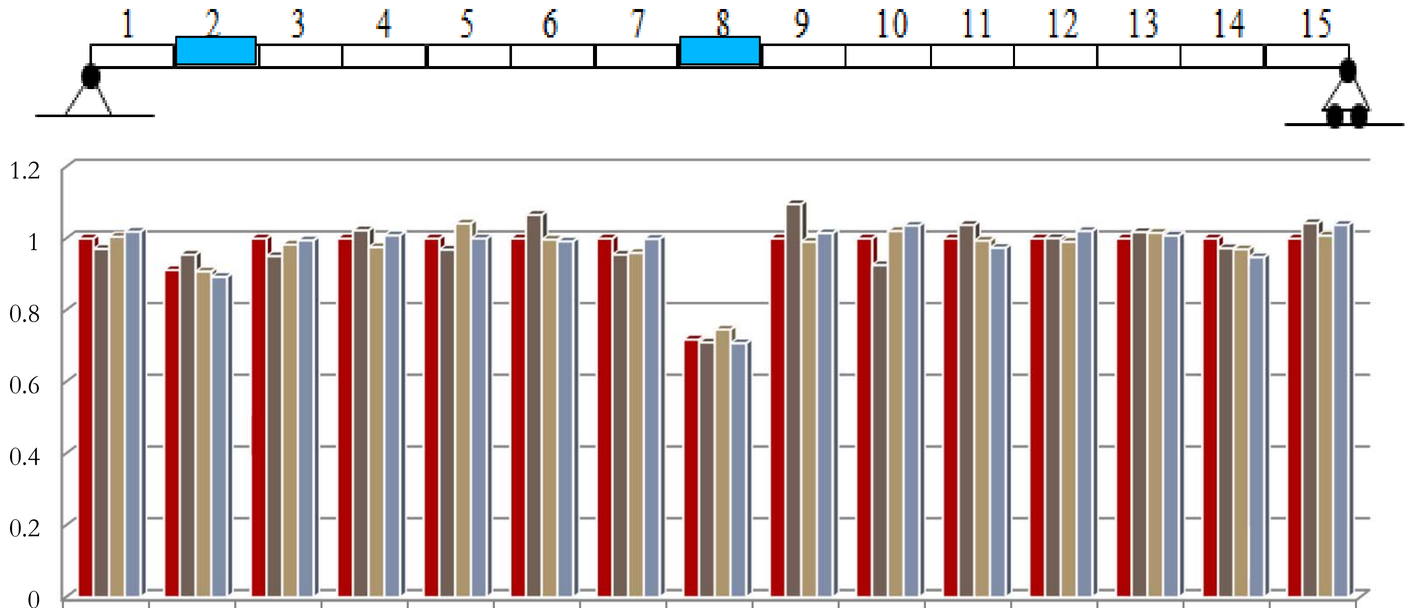
  - The probabilistic models used by EDAs can represent a priori information about the problem structure, allowing a more efficient search of optimal solutions.

  - Learning algorithms can also be used to reveal previously unknown information about the structure of black box optimization problems.

# Estimation of Distribution Algorithm



# Numerical Results




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| True value | 1 | 0.912 | 1 | 1 | 1 | 1 | 1 | 0.718 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| J1 | 0.971 | 0.955 | 0.951 | 1.023 | 0.969 | 1.066 | 0.955 | 0.71 | 1.096 | 0.926 | 1.038 | 1.001 | 1.018 | 0.973 | 1.043 |
| J2 | 1.005 | 0.908 | 0.983 | 0.976 | 1.042 | 0.997 | 0.96 | 0.746 | 0.991 | 1.021 | 0.994 | 0.991 | 1.016 | 0.97 | 1.008 |
| J3 | 1.019 | 0.893 | 0.995 | 1.009 | 1 | 0.992 | 0.999 | 0.708 | 1.015 | 1.036 | 0.974 | 1.021 | 1.008 | 0.948 | 1.038 |

- Numerical results using different objective functions

Y. Wang and T. Zhang (2013) “Finite element model updating using estimation of distribution algorithms” *6th International Conference on Structural Health Monitoring of Intelligent Infrastructure*, Hong Kong, China, 2013

# Discussions

- Finite element model updating is intrinsically an optimization process.

- Because of its superior capabilities on global optimization, EDA is introduced for model updating calculations.

- Numerical results on simple beam with multiple damages confirm that EDA is suitable for model updating.

# Approach 2

- Damage identification can be achieved via the following procedure
  - Model construction (training)
    - Build a train set with “fingerprint” of all accessible damage scenarios
  - Damage identification (pattern classification)
    - Compare the new unlabelled data to find its “closest-fit”

- This may eliminate the necessity of constructing a “perfect” numerical model.

# Damage Identification via Pattern Recognition

- Construct a feature matrix which includes "all" possible damage scenarios.

$$\mathbf{A} = [\mathbf{v}_{1,1}, \mathbf{v}_{1,2}, \ldots, \mathbf{v}_{1,n_1}, \mathbf{v}_{2,1}, \ldots, \mathbf{v}_{m,n_m}]$$

- Assume the new signal can be linearly represented by above matrix.

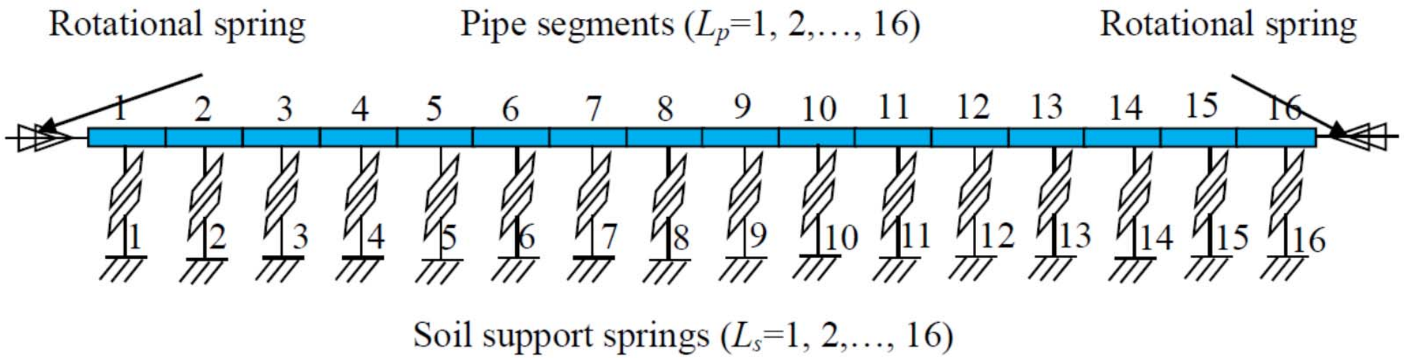
$$\mathbf{v} = \alpha_{j,1}\mathbf{v}_{j,1} + \alpha_{j,2}\mathbf{v}_{j,2} + \cdots + \alpha_{m,n_m}\mathbf{v}_{m,n_m}$$

- Damage identification problem is then converted to find the suitable vector $\alpha$


- Wang Y. and Hao H. 2013 "Damage Identification Scheme Based on Compressive Sensing", *Journal of Computing in Civil Engineering, ASCE*. 10.1061/(ASCE)CP.1943-5487.0000324 (May. 9, 2013).
- Wang Y. and Hao H. (2013) "Generalised damage identification scheme via sparse representation." *6th International Conference on Structural Health Monitoring of Intelligent Infrastructure*, 9th-11th December 2013, Hong Kong, China (invited talk)

# Numerical results

- Pipe-soil system




- The results show that even under 50% noise level (normal distribution), the method can still find the right damage type, location and severity.

# Experimental verification

- Although impact hammer testing included 15 sensors, only information from one sensor is used. The damage type and location are correctly identified.

# Discussions

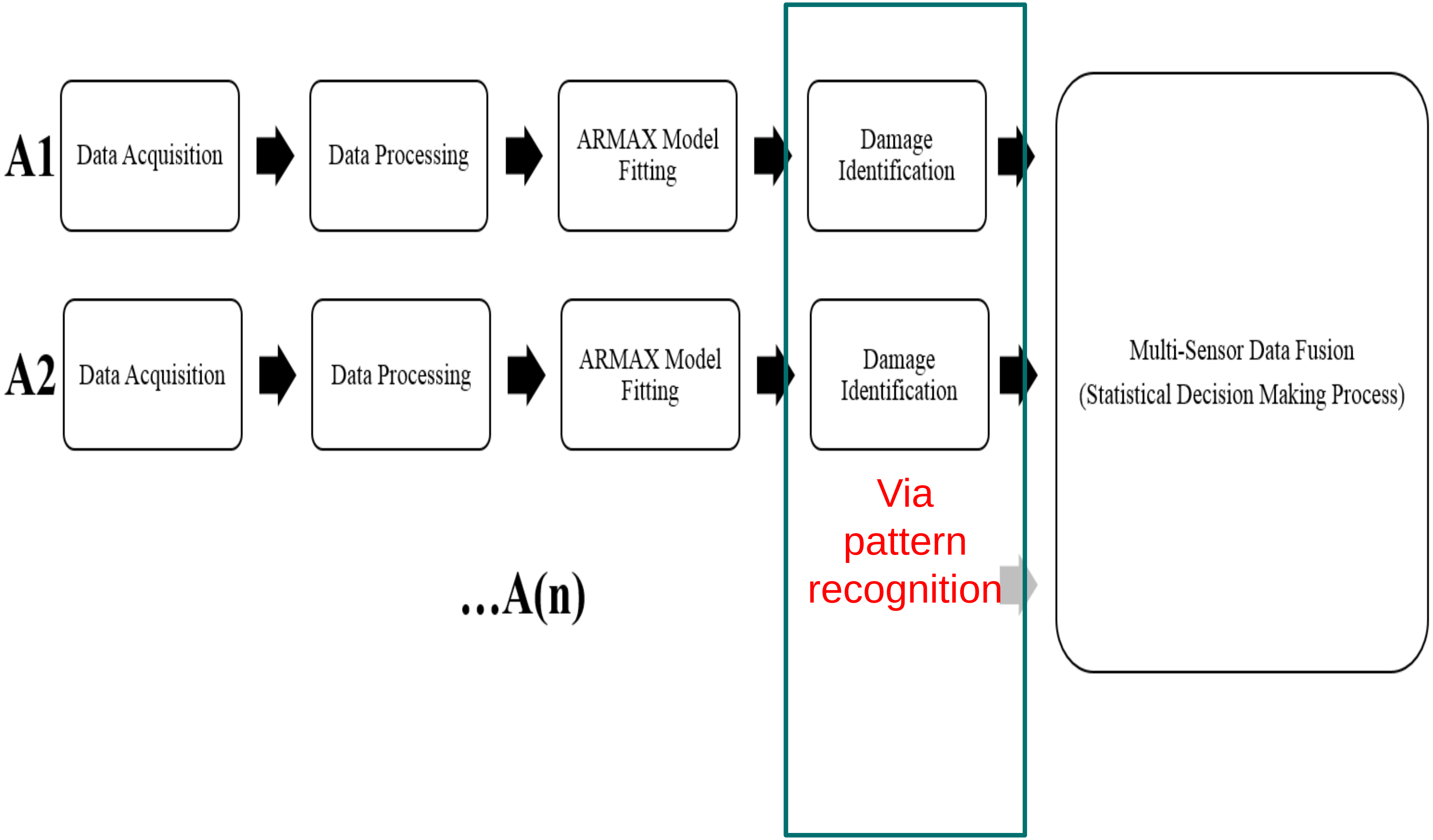
- Demonstrated by both numerical and experimental verification results, the proposed CS based damage identification scheme is robust, even under high noise level.

- Compared with traditional model updating approach, the proposed scheme requires less information, i.e., vibration time history of one point on the structure can yield good identification results.

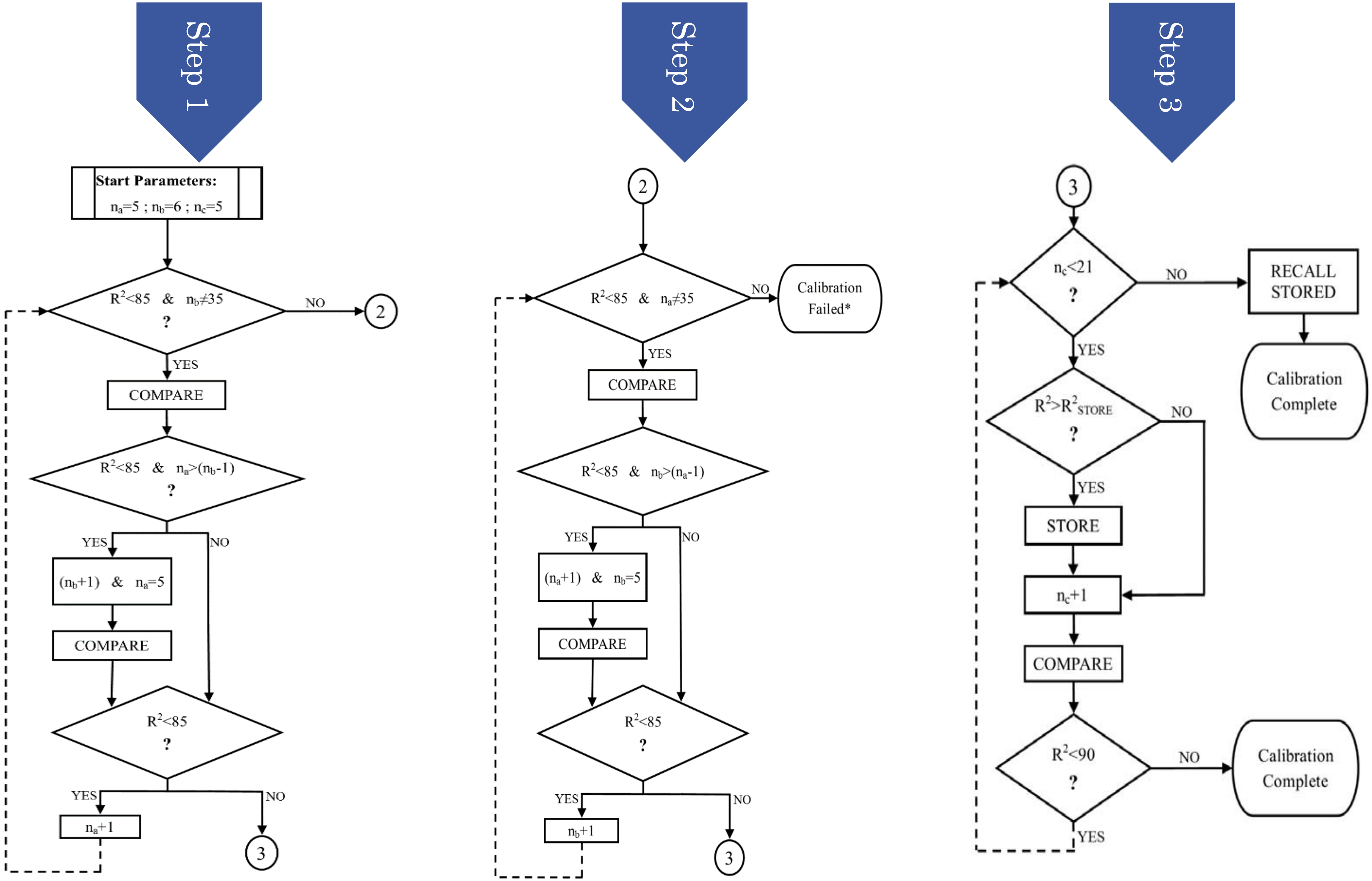
# Approach 3

- Nonlinear ARMAX model is chosen because of its capability to simulate complex and nonlinear dynamic behavior and to incorporate the disturbances created from the dynamic system.
- Deakin's contribution
  - Make it functional by proposing a self-fitting algorithm
  - Combine the information from different sensors by using data fusion

# Proposed methodology



# Self-fitting algorithm



# Case study on steel frame

- The proposed methodology is used to identify the right damage scenario based on experimentally acquired response signals.
- Three damage scenarios were testing
  I. Intact
  II. 2 bolts loosened
  III. 4 bolts loosened

# Results and Discussions

- The proposed methodology performs well by using the experimental results on steel frame. All the damage scenarios are correctly identified.

- A robust and efficient self-fitting algorithm is developed which can train ARMAX model based on experimental results.

- A multi-sensor data fusion scheme is used to increase the reliability of the final damage identification result.

Ay A.M., Wang Y., Khoo S.Y. and Li A.J. (2013) “Vibration based damage identification of a scale-model steel frame structure subjected to bolt connection failures.” *6th International Conference on Structural Health Monitoring of Intelligent Infrastructure*, 9th-11th December 2013, Hong Kong, China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