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Introduction

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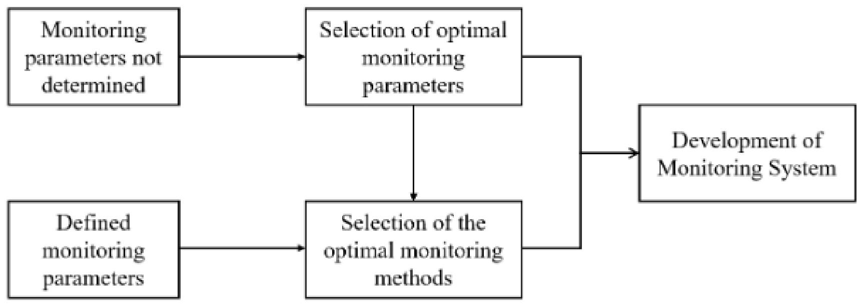
# Decision support system for structural health monitoring

The purpose of this decision support system is to help users select the appropriate structural health monitoring strategy for hybrid structures in use phase.




Decision Support System

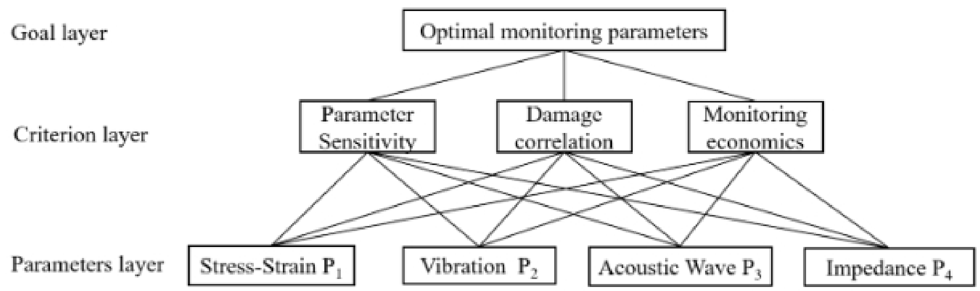
The decision process is conducted in two steps. The first step is the selection of the monitoring parameters using the Analytic Hierarchy Process (AHP) decision method. The second step is the selection of the monitoring method using the Rule based reasoning (RBR) decision method. The following figure shows the framework of the Decision Support System.

In the first step, a hierarchical model is created first. The monitoring parameters of the monitoring structure are used as decision objects. Parameters Sensitivity, Damage correlation, Monitoring Economy are used as indicators for the criteria and finally weights are calculated using the Analytic Hierarchy Process (AHP) decision method to determine the most appropriate monitoring parameters and recommend them to the user.

In the second step, the knowledge base (selection matrix) is compiled by analyzing the different monitoring methods based on the different attribute labels of the monitoring methods. Based on the information and desires of the decision maker, an "If-Then" statement is used to determine the best monitoring method.

# Optimal monitoring parameter selection

The Analytic Hierarchy Process (AHP) methode was used to select appropriate monitoring parameters with three criteria, namely **Parameter Sensitivity, Damage Correlation**, and **Monitoring Economy**, followed by a comparison of the weights of each two.




AHP hierarchical structure

## Monitoring parameters selection criteria

*Parameter Sensitivity*: Reflects the sensitivity of the monitoring parameters to the degradation process of the system health condition, the more sensitive the parameters are, the easier it is to capture the performance degradation state of the structure

*Damage correlation*: Monitoring parameters can reflect multiple health state performance of the structure (reflecting the type of damage).

*Monitoring economics*: The cost price to be paid for monitoring, including monitoring cost, information transmission and processing cost, operation cost and labor cost, etc.

## Parameter Criterion Importance Assessment

Please follow the 1-9 importance scale table in the figure to assess the importance of the three criteria of the monitored parameters according to your needs.

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 3 | Moderate importance | Experience and judgment slightly favour one over another |
| 5 | Strong importance | Experience and judgment strongly favour one over another |
| 7 | Very strong importance | Activity is strongly favoured and its dominance is demonstrated |
| 9 | Absolute importance | Importance of one over another affirmed on the hightest posiible order |
| 2, 4, 6, 8 | Intermediate values | Use to represent compromise between the priorities listed above |
| Reciprocal of above non-zero numbers | If activity ***i*** has one of the above non-zero numbers assigned to it when compared with activity ***j***, then activity ***j*** has the reciprocal value when compared with ***i*** | |

1-9 importance scale

## For monitoring parameters, which monitoring parameter criterion is more important. Please make a choice

1. (A) Parameter Sensitivit compared to (B) Damage Correlation

1

9 1/9

Your choice is: **A and B** Equal importance

2. (A) Parameter Sensitivity compared to (B) Monitoring Economy

3

9 1/9

Your choice is: **A** Moderate importance

3. (A) Damage Correlation compared to (B) Monitoring Economy

3

9 1/9

Your choice is: **A** Moderate importance

Click to determine optimal monitoring parameters

**Criterion Layer**

Criterion Layer Weight = [0.42857143 0.42857143 0.14285714]

Maximum Eigenvalue = 3.000000

Relative consistency index (CR) = -0.000000

Consistency check passed

**Parameter layer**

| | Stree-Strain | Vibration | Acoustic Wave | Impedance | Maximum Eigenvalue | CR | Consistency check |
|---|---|---|---|---|---|---|---|
| Parameter Sensitivity | 0.1667 | 0.1667 | 0.3333 | 0.3333 | 4.0000 | 0.0000 | true |
| Damage Correlation | 0.1272 | 0.2804 | 0.3120 | 0.2804 | 4.0206 | 0.0061 | true |
| Monitoring Economy | 0.4039 | 0.3404 | 0.1166 | 0.1391 | 4.0310 | 0.0092 | true |

**Goal layer**

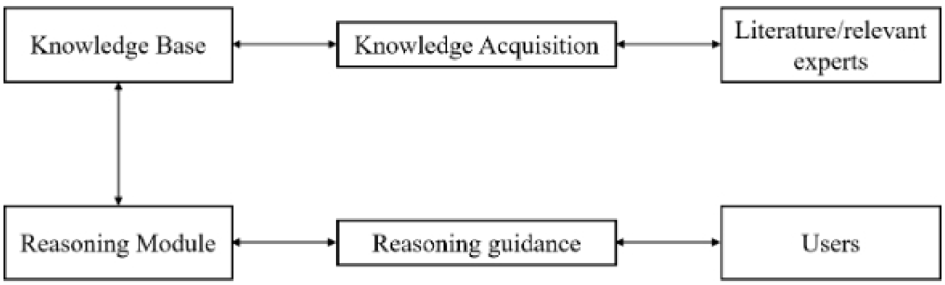
Parameter weights: [0.18366011 0.24022046 0.29323988 0.28287955]

The parameters are sorted as Acoustic Wave, Impedance, Vibration, Stree-Strain

The optimal parameters are: Acoustic Wave

# Optimal monitoring method selection

The second step is the selection of the monitoring method, using the Rule based reasoning (RBR) decision method. First, The knowledge base (selection matrix) is compiled by analyzing the different monitoring methods based on the different attribute labels of the monitoring methods. Based on the information and desires of the decision maker, an 'If-Then' statement is used to determine the best monitoring method.




Rule based reasoning decision system

## Alternative monitoring methods

In the following tables, the alternative monitoring methods in the knowledge base are presented, along with their strengths and weaknesses.

| Method | Advantage | Limitation |
|---|---|---|
| **Natural frequency** | Easy to implement; Cost effective; High sensitivity to damage. | Environmental factors; Errors in measurements |
| **Modal Shape - Curvature** | Suitable for online monitoring; less affected by the environment | Small identification range; Only reveal damage boundary location |
| **Frequency response function** | Simple to implement; Sensitive to local changes in structures; | Unable to locate accurately; Errors inmeasurements |
| **Stress-based** | High accuracy and fast monitoring | Cannot detect small damages; Small identification range |
| **Electromechanical Impedance (EMI)** | Sensitive to small damages; Cost effective; Suitable for both on-site and offsite monitoring | Insensitive to far-field damage and bound-ary conditions; Accuracy influenced by sensor location |
| **Lamb wave based** | Cost effective; High flexibility; Suitable for Online monitoring; Travels over long distances; Monitor large area | Dispersive nature; Multiple waveforms; Skilled personnel required |
| **Artificial intelligence algorithm based** | Mimic a structure; High processing speed; Images of damage; Realtime operation | Skilled personnel required; Large data base needed; Complex solutions consume a lot of time |

SHM Methods

# Selection of attributes for monitoring method

Please select the attributes related to the monitoring method according to the actual situation and wishes

## 1. Please select the material of hybrid structure

The metal materials in the hybrid structure is

Non-magnetic metal

The non-metallic materials in the hybrid structure is

Composites

The hybrid structural materials are Non-magnetic metal and Composites

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## 2. Please select monitoring parameters

The monitoring parameter of this monitoring system is:

Acoustic Wave

The monitored parameter is Acoustic Wave

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## 3. Please select the data processing method

The system's data processing method is:

Time-frequency domain

The system's data processing method is Time-frequency domain

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## 4. Please select the Monitoring range

The Monitoring range is:

Global and Local

The system's Monitoring range is: Global and Local

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## 5. Please select the Monitoring mode

The system monitoring type is:

Active

The system's monitoring mode is: Active

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## 6. Please select the Damage analysis function

The system damage analysis functions are:

Detection × Location × Assessment ×

The system's Damage analysis functions are: Detection, Location, Assessment

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## 7. Please select other influence factors

Other factors of the system:

Identification Accur... × Environmental Factor × Cost Effectiveness ×

Other factors of the system are: Identification Accuracy, Environmental Factor, Cost Effectiveness

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Click to determine optimal monitoring method

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## Recommended order of monitoring methods

Lamb Wave, Frequency response function, Electro Mechanical Impedance, Stress based, Artificial Intelligence, Mode Shape-Curvature, Natural Frequency

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## Decision result for monitoring method

Non-recommended monitoring methods: Natural Frequency, Mode Shape-Curvature

Optimal monitoring method is: Lamb Wave

## References of optimal monitoring method

Zhao, X., Royer, R. L., Owens, S. E., & Rose, J. L. (2011). Ultrasonic lamb wave tomography in structural health monitoring. *Smart Materials and Structures*

Wang, S.,Wu,W., Shen, Y., Liu, Y., & Jiang, S. (2020a). Influence of the pzt sensor array configuration on lamb wave tomography imaging with the rapid algorithm for hole and crack detection. *Sensors*