EXPERIMENTAL STUDY OF SOURCE LOCALIZATION IN ACOUSTIC EMISSION USING TRIANGULATION METHOD

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ABSTRACT: Conventional repair and rehabilitation techniques have proven effective only to treat damage and arrest it. Hence, the need to prevent the damage, to know the growing damage before a complete collapse is necessary. Thus, acoustic emission is a proven method for structural health monitoring, to find and rectify the damage at its early stage. The Acoustic emission technique could be directly applied for monitoring large structures made of concrete, aircrafts & bridges. It helps in recognition of structural damage prior, which helps in avoiding catastrophic failure. The proper and efficient detection of damage makes structure safer for the public. This is a low-cost & less intricate technique than conventional methods. Quantitative criteria of acoustic sensing will provide efficient diagnosis and prognosis of structural damage. This paper surmounts the triangulation method of source localization of acoustic emission. The data is gathered by the sensors and then used to know the location of damage/source and respective characteristics of the wave. MATLAB is used for defining the energy of the signals captured by the sensors. Thus, the signal parameter’s study and verification of the source’s location using sensors is justified to be correct in the acoustic emission technique.

Keywords: Acoustic emission, Source localization, Triangulation method, Non-destructive method, Sensors

Introduction:

Acoustic emission is a type of SHM (Structural Health Monitoring), for actual-time status assessing structures. In this evaluation for generating an oscillatory movement within atoms, the load provided in the sample, this is done to have some dynamic events inside the sample, which in return creates stress waves that spread across the sample and come out, and the sensor pick up on these waves. (figure:1).

Generally, the intensity of this emission is very low so, these waves are sent to the preamplifier, after which these waves are sent to the transducer to change the elastic/acoustic waves into electrical signals.
based on the energy of recorded signals from each transducer in a specified array, it’s determinable the location of incidence in the test area.

The objective of the research is to comprehend the AE signal by studying the parameters (table :1) of the same wave signal captured by different sensors having varied arrival timings and to try to locate the source of damage using the 2D localization principle. The benchmark data available online is used for numerical validation.

**Signal Parameters:**

The signal parameters are studied in this technique to have a better understanding of the source (Figure: 2).

- **Amplitude**: It is defined as the source’s magnitude and is usually denoted by the highest peak of voltage signal; it’s denoted by “A”

| PARAMETER                  | INFORMATION ABOUT THE SOURCE EVENT                                      |
|----------------------------|-------------------------------------------------------------------------|
| Rate                       | the frequency with which damage occurs                                  |
| Peak amplitude             | source event intensity, direction                                       |
| Relative arrival times     | source’s location                                                       |
| Duration                   | source event's energy                                                   |
| Waveform                   | source energy structure                                                 |
| Energy                     | Type of damage caused by the energy of the source event                  |

Table: 1- Parameter and source event

- **Counts**: It is the number of the pulse emitted when the signal’s amplitude is larger than the threshold; it's denoted by “N”[5]

**Figure**: 2 – Signal Parameters

- **Hits**: A hit is often a signal that creates a situation, farming a system, which the data is accumulated by the channel. It’s a description of an AE occurrence. The event rate is measured as the number of hits per unit of time. Both the number of hits and the quantity of counts are used to determine the quantity of an AE. [5]
• Rise Time: It's the time between the initial threshold crossing and the maximum amplitude of the signal; it's symbolized by the letter "R"[5].
• Duration: It's described as a period of time between a signal trigger. It can also be described as then time to reduce below the threshold value; It denoted by 'D'
• Threshold: This is the setup setting for comparing electronic background sounds. With low-frequency waves, to regret background noise

Related Studies:
When referring to several publications, it is mentioned that the method of acoustic emission is used for diverse applications like monitoring structural materials, composites, steel structures, bridges, ceramics, and so on. Multiple sensors are placed across cite a relevant source for appraise the damage source.[1]

• AE technique has a diverse set of uses from civil engineering to the aerospace sector. It is used in real-time surveillance of the structures to identify any sudden changes in the element, to indicate situation of the gear in automobiles, to check tool conditions (wear) in machinery, to monitor components of airplanes such as wings, engine connections, etc.[2]

• It also has some limitations. This technique doesn't detect cracks that are present, the sensors capture signals of a particular frequency range (30-300 kHz), it also captures noise signals along with the signals via damage, and it does not apply to heterogeneous materials and can obtain a qualitative report of the damage only. Quantification of the damage using AE is currently under study.[6]

Methodology:
The AE signal processing begins with calculating the basic parameters of the signal like hit, rise time, duration, amplitude, energy, counts of the signal captured by the sensors. This gives us a rough idea about the source’s location, as higher the value of amplitude/energy, when closer to source. Now, to determine the position of the source, 2D localization is followed. Calculating the values of Δt, R, c, D the location of the source (Xs, Ys) can be determined.

Experimental Results:
Procedure for 2D Acoustic Source Localization with three sensors using Triangulation method:

1. X and Y-axis coordinates of the three sensors (figure 4), captures the AE wave, generated to damage are first measured by setting datum.
2. The distance in middle of three sensors, In.e.g. Between sensor 1& 2, sensor 1&3 is computed using distance formula with known X, Y coordinates from step 1 (figure 3a and 3b)
3. Form a triangle between the three sensor coordinates and compute theta1 and theta3.
4. The Threshold of the AE to eliminate noise is chosen
5. Arrival time (the first time instant at which AE wave crosses the threshold) of three sensors is estimated.
6. Estimate deltat1 and deltat2 in.e.g. The variation arrival times between sensor 1 &2, sensor 1&3
7. Estimate the wave speed by properties of structure is considered.e.g. through Young's modulus, density, and the Poisson ratio of material & the type of wave (p wave, s wave, etc)
8. Estimation of is R based on D1 and D2 and other parameters of step 8 by equations (1) and (2)
9. Substitute estimated R in Xs and Ys equation, which result in two equations due to equations of R each for X-axis and Y-axis, In.e.g. Totally 4 equations
10. Final step is to find theta for which the solution of the Xs and Ys (above equations of step 9) has a minimum error.
11. Substitute theta and get Xs and Ys i.e. Source localization
12. Compare the assumed location to known true location to evaluate the accuracy of the proposed technique
Figure 3a: Pictorial representation of the sensor locations

Figure 3b: Front view of concrete block

Implementation – Triangulation method:

\[
\Delta t_1 = r_1 R \\
Z = R \sin \theta \\
Z_2 = r_2 - (D \times R \cos \theta)^2 \\
R = \frac{(D_1 \Delta t_1 \sin^2 \theta)}{2(\Delta t_1 v + \theta - \theta_1)}
\]
Similarly, between S1 and S3

\[
R = \frac{(D^2 - 2 \Delta t^2 + \theta^2)}{2(\Delta t^2 + (\theta^3 - \theta))}
\]

Where,

V, the velocity of sound

\( \Delta t \), time differences between S1-S2 and

\( \Delta t^2 \), time differences between S1-S3 sensor signals arrival time

![Graphical representation of sensor location](image)

**Figure 5:** Graphical representation of sensor location

Here,

Y is the abscissa

Z is the ordinate

Renaming the sensors 15, 16 and 17 to be 1, 2 and 3 respectively,

\[
(Z_1, y_1) = 6.5, 84
\]

\[
(Z_2, y_2) = 64, 23
\]

\[
(Z_3, y_3) = 27.5, 23
\]

Let

\( D_1 \) = distance between sensor 3 and 1

\( D_2 \) = distance between sensor 3 and 2

Therefore,

\[
D_1 = [(Z_3 - Z_1)^2 + (Y_3 - Y_1)^2]^{1/2}
\]

\[
= 58.86\text{cm}
\]
And,
\[ D_2 = \sqrt{\left( Z_3 - Z_2 \right)^2 + \left( Y_3 - Y_2 \right)^2} \]
\[ = 36.5\text{cm} \]
\[ \theta_1 = \tan^{-1} \left( \frac{Y_1 - Y_3}{X_1 - X_3} \right) \]
\[ = -16.28 \]
\[ \theta_3 = \tan^{-1} \left( \frac{Y_2 - Y_3}{X_2 - X_3} \right) \]
\[ = 0 \]

From the data collected
\[ t_1 = 2.130604744 \]
\[ t_2 = 2.130561352 \]
\[ t_3 = 2.130635262 \]

Let,
\[ \Delta t_1 = t_2 - t_3 = -3.052 \times 10^{-5} \]
\[ \Delta t_2 = t_1 - t_3 = -7.391 \times 10^{-5} \]

Assume \( c = 3000 \text{ cm/s} \)

\( \Delta t_1 \) and \( \Delta t_2 \) are time differences \((t_2 \cdot t_1)\) and \((t_3 \cdot t_1)\) and \( c \) is the wave speed.

Using these equations,
\[ d_{11} = \frac{D_1^2 - \Delta t_1^2 \cdot c^2}{2(\Delta t_1 \cdot c + D_1 \cdot \cos(\theta - \theta_1))} \]
\[ d_{12} = \frac{D_2^2 - \Delta t_2^2 \cdot c^2}{2(\Delta t_2 \cdot c + D_2 \cdot \cos(\theta_3 - \theta))} \]
\[ d_{11} = 34.71\text{cm} \]
\[ d_{12} = 19.045\text{cm} \]

The source location is calculated by:
\[ X_s = X_1 + R_{11} \cos \theta \]
\[ Y_s = Y_1 + R_{11} \sin \theta \]
Hence,

\[
X_s = 61 \text{ cm} \\
Y_s = 18 \text{ cm}
\]

**Observation:**

The hit, amplitude, rise time, duration, energy, counts of the wave apprehend from sensors 15, 16, and 17 are tabulated below concerning source B.

| Sensor | Arrival Time (s) | Threshold (v) | Hit | Amplitude (v) | Amplitude (dB) | Rise Time (s) | Duration (s) | Energy (E) | Avg. Energy | Count |
|--------|------------------|----------------|-----|---------------|----------------|---------------|--------------|------------|-------------|-------|
| 15     | 2.13060          | 4744           | 1   | 0.0147        | 83.3463466     | 0.000          | 0.00096      | 3.20E-06   | 367         |       |
|        |                  | 5.55586        | 2   | 0.011         | 80.8278537     | 0.000          | 0.00097      | 3.00E-06   | 349         |       |
|        |                  | 9103           | 3   | 0.0125        | 81.9382002     | 0.000          | 0.00098      | 1.90E-06   | 419         |       |
|        | 8.91807          | 1747           | 4   | 0.017         | 84.6089784     | 0.000          | 0.00098      | 2.40E-06   | 376         |       |
|        | 12.5132          | 8182           | 5   | 0.012         | 81.5836249     | 0.000          | 0.00097      | 2.50E-06   | 360         |       |
|        | 16.0266          | 7236           | 6   | 0.011         | 81.3637172     | 0.000          | 0.00095      | 2.00E-06   | 361         |       |
|        | 19.6219          | 5396           | 7   | 0.013         | 82.4114786     | 0.000          | 0.00096      | 2.80E-06   | 374         |       |
|        | 23.1376          | 0376           | 8   | 0.0115        | 81.2139568     | 0.000          | 0.00095      | 2.70E-06   | 369         |       |
|        | 27.0907          | 8407           | 9   | 0.0043        | 72.66093691    | 0.000          | 0.00098      | 1.90E-06   | 352         |       |
|        | 30.9183          | 1398           | 10  | 0.0042        | 72.4649858     | 0.000          | 0.00096      | 2.50E-06   | 391         |       |
|        | 44.3102          | 8366           | 16  | 0.0163        | 84.2437520     | 0.000          | 0.00099      | 3.00E-06   | 341         |       |
|        |                  | 2.13056        | 2   | 0.0124        | 81.8684337     | 0.000          | 0.00099      | 1.80E-06   | 300         |       |
|        |                  | 5.55582        | 3   | 0.0137        | 82.7344113     | 0.000          | 0.001        | 1.70E-06   | 317         |       |
|        |                  | 2849           | 4   | 0.0176        | 84.9102533     | 0.000          | 0.001        | 2.30E-06   | 355         |       |
|        |                  | 8.91802        | 5   | 0.0124        | 81.8684337     | 0.000          | 0.001        | 2.30E-06   | 301         |       |
|        |                  | 5971           | 6   | 0.0119        | 81.5109392     | 0.000          | 0.00099      | 1.87E-06   | 278         |       |
|        |                  | 12.5132        | 7   | 0.015         | 83.5218251     | 0.000          | 0.00099      | 2.50E-06   | 318         |       |
|        |                  | 3891           | 8   | 0.0126        | 82.0074109     | 0.000          | 0.001        | 2.30E-06   | 293         |       |
|        |                  | 16.0266        | 9   | 0.0161        | 84.1365175     | 0.000          | 0.001        | 1.80E-06   | 315         |       |
|        |                  | 2277           | 10  | 0.0163        | 84.2437520     | 0.000          | 0.001        | 2.10E-06   | 336         |       |
|        |                  | 19.6219        | 17  | 0.0061        | 75.7065967     | 0.000          | 0.001        | 1.30E-06   | 329         |       |
|        |                  | 5262           | 2   | 0.0049        | 73.8039216     | 0.000          | 0.00099      | 9.10E-07   | 300         |       |
|        |                  | 8.91809        | 3   | 0.0051        | 74.1514035     | 0.000          | 0.00099      | 8.30E-07   | 322         |       |
|        |                  | 6542           | 4   | 0.0071        | 77.0251669     | 0.000          | 0.001        | 1.20E-04   | 336         |       |
|        |                  | 12.5133        | 5   | 0.0048        | 73.6248247     | 0.000          | 0.00099      | 1.10E-06   | 299         |       |
|        |                  | 1234           | 6   | 0.0046        | 73.2551566     | 0.000          | 0.00099      | 5.40E-06   | 276         |       |
From tabular column 1 that the sensor (16), closest to source (damage), has recorded the highest amplitude and energy. It helps us to place more sensors near that location to get an accurate the source's location, and ultimately the source's location has been determined using a 2D localization procedure almost to the expected value.

| Table 3: 2D localization results |
|---------------------------------|
| **Values** | **Xs (cm)** | **Ys (cm)** |
| Expected value | 55.9 | 15.2 |
| Calculated value | 61 | 18 |

Thus, acoustic emission’s technique proven to be helpful to locate the damage in structures by working on the data collected by the sensors.

Significant results and discussion:

Based on the results of the numerical analysis, using benchmark data, it’s concluded that the energy and amplitude of signal provides information about location of the source. It may help to replace sensor positions for accurate localization. 2D Triangulation can identify source’s location with minimal error. It can be minimized largely by collecting AE measurements by repeated tests on the structure under consideration.

Conclusions:

Being in the fast-paced era, infrastructure development in the countries has grown up dramatically, there’s an emerging need for proper monitoring of the structures, to benefit in longer run. Conventional techniques of repair and rehabilitation are effective, when the damage is identified correctly. Hence the need to detect the progressing damage in structures to avert devastating effects is necessary.

Acoustic emission techniques are considered to be a non-destructive method in structural health monitoring. It uses sensors gather the acoustic waves from material whenever there’s change in the temperature, stress levels, and so on from developing cracks. This technique can be implemented with few sensors, localizes acoustic source, for huge 3D structures too. The data is collected by the sensors is then comprehend the location of damage/source and respective characteristics of the wave. From the numerical studies, the parameter study of the signal and triangulation procedure adopted for localization of damage is proven to be robust. MATLAB is added to work for implementation and validation.

Future Scope of work:
The future work will be on the extension of the 2D procedure to 3D implementation. Simulation of 3D structures will be realized via Finite Element Method as it can model any complex structure.

References:

[1] B. W. Jang and C. G. Kim, “Acoustic emission source localization in composite stiffened plate using triangulation method with signal magnitudes and arrival times,” *Adv. Compos. Mater.*, vol. 00, no. 00, pp. 1–15, 2020, doi: 10.1080/09243046.2020.1786903.

[2] C. B. Scruby, “An introduction to acoustic emission,” *J. Phys. E.*, vol. 20, no. 8, pp. 946–953, 1987, doi: 10.1088/0022-3735/20/8/001.

[3] “acoustic-emission @ www.sciencedirect.com.” [Online]. Available: https://www.sciencedirect.com/topics/chemistry/acoustic-emission.

[4] “Acoustic-emission-testing @ www.twi-global.com.” [Online]. Available: https://www.twiglobal.com/technical-knowledge/faqs/acoustic-emission-testing.

[5] M. Kaphle, “Analysis Of Acoustic Emission Data For Accurate Damage Assessment For Structural Health Monitoring,” pp. 5–21, 2012.

[6] A. Krampikowska, R. Pala, I. Dzioba, and G. Śwint, “The use of the acoustic emission method to identify crack growth in 40CrMo steel,” *Materials (Basel).* vol. 12, no. 13, pp. 1–14, 2019, doi: 10.3390/ma12132140.

[7] R. Madarshahian, V. Soltangharaei, R. Anay, J. M. Caicedo, and P. Ziehl, “Hsu-Nielsen source acoustic emission data on a concrete block,” *Data Br.*, vol. 23, p. 103813, 2019, doi: 10.1016/j.dib.2019.103813.

[8] S. Mindess, “Acoustic emission and ultrasonic pulse velocity of concrete,” *Int. J. Cem. Compos. Light. Constr.*, vol. 4, no. 3, pp. 173–179, 1982, doi: 10.1016/0262-5075(82)90043-4.

[9] B. W. Jang and C. G. Kim, “Acoustic emission source localization in composite stiffened plate using triangulation method with signal magnitudes and arrival times,” *Adv. Compos. Mater.*, vol. 00, no. 00, pp. 1–15, 2020, doi: 10.1080/09243046.2020.1786903.