Int. J. Sci. R. Tech., 2026 3(1)
A Multidisciplinary peer-reviewed Journal
www.ijsrtjournal.com [ISSN: 2394-7063]

Original Article

Energy-Weighted TDOA Method for Acoustic Leak Localization in Monophasic Fluid Pipelines

Setra Rakotoarimanga*, Elisée Rastefano

EAD SE-I-SMDE, ED-STII, University of Antananarivo, Madagascar

ABSTRACT

Acoustic emission techniques have become an effective solution for monitoring and leak detection in fluid transport pipelines, mainly due to their non-intrusive nature and high sensitivity. Among these approaches, localization based on the Time Difference of Arrival (TDOA) is widely used; however, its accuracy is often limited by measurement noise and unequal sensor contributions, particularly in realistic industrial environments. This paper proposes an energy-weighted TDOA method to enhance the accuracy and robustness of acoustic leak localization in monophasic fluid pipelines. The proposed approach integrates the acoustic energy received by each sensor into the localization process, giving greater importance to sensors closer to the leak source, where the signal is generally more reliable. A weighted cost function is formulated and solved using numerical optimization techniques. The method is evaluated through numerical simulations conducted under both ideal and noisy conditions. Gaussian noise is introduced to represent realistic uncertainties in time-of-arrival measurements, and Monte-Carlo simulations are carried out to assess the statistical robustness of the proposed method. The results show that, while the classical TDOA approach performs well in noise-free scenarios, its accuracy rapidly degrades in the presence of noise. In contrast, the energy-weighted TDOA method achieves higher localization accuracy, lower error dispersion, and improved robustness. These results confirm the relevance of the proposed approach for practical pipeline monitoring applications.

Keywords: Acoustic emission, Leak localization, Time Difference of Arrival (TDOA), Energy-weighted localization, Monophasic fluid pipelines, Sensor networks, Monte-Carlo simulation

INTRODUCTION

Fluid transport pipelines play a critical role in industrial infrastructures such as water distribution networks, oil and gas transportation systems, and chemical process plants. Despite their importance, these systems are highly vulnerable to leaks caused by corrosion, mechanical degradation, manufacturing defects, or accidental damage. Even small leaks, if not detected at an early stage, may lead to significant economic losses, environmental pollution, and safety hazards. Consequently, the development of reliable and efficient leak detection and localization techniques remains a major concern for pipeline operators [1][2][3]. Among the various techniques proposed in the literature, acoustic emission-based methods have gained considerable attention due to their non-intrusive nature and their ability to detect leaks without interrupting system operation [4][5]. A leak generates turbulent flow and pressure fluctuations, which produce acoustic waves that propagate along the fluid and the pipe wall. By capturing these signals using a network of acoustic sensors, it becomes possible not only to detect the presence of a leak but also to estimate its location along the pipeline [6]. Localization methods based on the Time Difference of Arrival (TDOA) are widely used in this context [7][8]. The principle relies on measuring the arrival times of the acoustic signal at different sensors and estimating the source position by exploiting the time delays between sensors. While TDOA-based localization is conceptually simple and computationally efficient, its performance strongly depends on the accuracy of the measured arrival times and the quality of the recorded signals. In practical conditions, acoustic signals are often affected by environmental noise, signal attenuation, dispersion, and reflections, which significantly degrade localization accuracy [9] [10]. A major limitation of classical TDOA approaches lies in the implicit assumption that all sensors contribute equally to the localization process. In reality, sensors located farther

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

from the leak receive weaker signals with lower signal-to-noise ratios, making their measurements more sensitive to noise and uncertainty. Treating all sensors with equal importance may therefore lead to biased estimations or even unstable solutions, especially in noisy environments or when the sensor layout is non-uniform [11] [12]. To address these limitations, this paper proposes an energy-weighted TDOA localization method for acoustic leak detection in monophasic fluid pipelines. The core idea is to incorporate the acoustic energy received by each sensor into the localization process, allowing sensors with stronger and more reliable signals to have a greater influence on the estimation. This weighting strategy is physically motivated by the attenuation of acoustic energy with distance and provides a natural way to reduce the impact of noisy or weak measurements. The proposed method formulates a weighted cost function that combines time-of-arrival information with energy-based weighting and solves the localization problem using numerical optimization techniques. The performance of the method is evaluated through two-dimensional and three-dimensional numerical simulations under both ideal and noisy conditions. In addition, Monte-Carlo simulations are conducted to assess the statistical robustness of the approach and to compare it with the classical TDOA method.

The main contributions of this paper can be summarized as follows:

- The formulation of an energy-weighted TDOA localization model with a clear physical interpretation.
- The integration of acoustic energy information into the localization process to improve robustness against measurement noise.
- A comprehensive numerical validation under both ideal and noisy conditions, including statistical evaluation based on Monte-Carlo simulations.
- A quantitative comparison between the classical TDOA method and the proposed energy-weighted approach.

The remainder of this paper first presents the modeling of the acoustic leak signal and the formulation of the localization problem. The classical TDOA localization approach and its main limitations are then discussed. Next, the proposed energy-weighted TDOA method is introduced and detailed. The numerical simulation framework and the corresponding results are subsequently presented and analyzed. The paper concludes with a summary of the main findings and perspectives for future work. Figure 1 illustrates the general principle of acoustic leak localization using multiple sensors distributed along a pipeline.

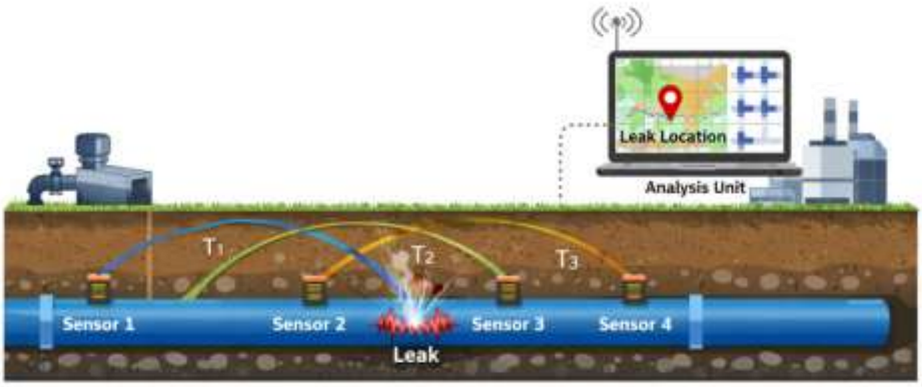

Figure 1: General illustration of an acoustic leak localization system using multiple sensors along a pipeline.

MATERIALS AND METHODS:

Acoustic signal modeling and problem formulation

Acoustic leak detection in fluid pipelines relies on the physical phenomenon whereby a leak generates pressure fluctuations and turbulent flow at the leakage point. These disturbances produce acoustic waves that propagate along the fluid medium and through the pipe wall. The characteristics of the generated signal depend on several factors, including the internal pressure, the leak size, the fluid properties, and the mechanical characteristics of the pipeline [4][6].

➢ Acoustic Signal Generated by a Leak

When a leak occurs, the sudden pressure drop and turbulent jet flow create broadband acoustic emissions. These signals are typically characterized by a wide frequency spectrum and non-stationary behavior, making them distinguishable from background operational noise under favorable conditions. The acoustic energy radiated from the leak decreases with distance due to geometric spreading and material attenuation along the pipeline [5][9]. Let the position of the leak source be denoted by the spatial coordinates (x, y, z). The acoustic signal propagates toward each sensor at a velocity approximately equal to the speed of sound in the fluid. As a result, sensors located closer to the leak receive signals with higher energy and better signal-to-noise ratios, while distant sensors are more affected by attenuation and ambient noise [6] [10].

➢ Propagation Model and Time of Arrival

Assuming a homogeneous monophasic fluid and a constant propagation velocity c, the arrival time of the acoustic signal at the i-th sensor located at (x_i, y_i, z_i) can be expressed as:

$$t_i = t_0 - \frac{d_i}{C}$$

where t_0 is the unknown emission time of the acoustic event and d_i represents the Euclidean distance between the leak source and the sensor:

$$d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2}$$

In practice, the measured arrival times are affected by noise and uncertainties related to sensor sensitivity, signal attenuation, and environmental disturbances. These factors introduce errors in the estimation of t_i, which directly impact the accuracy of time-based localization methods [7][9].

➢ Time Difference of Arrival Formulation

To eliminate the unknown emission time t_0 localization approaches based on the Time Difference of Arrival (TDOA) exploit the relative arrival times between sensor pairs. The time difference between sensors i and j can be written as:

$$\Delta t_{ij} = t_j - t_i = \frac{d_i - d_j}{C}$$

This formulation defines a set of nonlinear equations whose solution corresponds to the leak position. Geometrically, each TDOA equation represents a hyperboloid (or a hyperbola in two-dimensional cases), and the intersection of multiple such surfaces yields the estimated source location [7][8].

➢ Problem Statement and Limitations

In classical TDOA-based localization, all sensors are treated equally when solving the system of equations. However, this assumption does not reflect physical reality, since the reliability of the measured arrival times varies from one sensor to another. Sensors receiving low-energy signals are more sensitive to noise, which can lead to biased estimations or poor convergence of numerical solvers, especially in noisy environments [1]. Consequently, the localization problem can be formulated as an optimization task that seeks to minimize the discrepancy between the modeled and measured arrival times across all sensors. Improving the robustness of this formulation requires accounting for the unequal contribution of sensors, which motivates the introduction of an energy-weighted approach, detailed in the following part of this paper.

Classical TDOA localization method

The Time Difference of Arrival (TDOA) method is one of the most commonly used techniques for acoustic source localization in pipeline monitoring applications. Its popularity stems from its relatively simple formulation, low computational cost, and suitability for distributed sensor networks. In the context of leak detection, TDOA exploits the differences in arrival times of acoustic signals measured by spatially separated sensors to estimate the location of the leak source [7][8].

➢ Principle of Classical TDOA Localization

The fundamental principle of classical TDOA localization relies on measuring the arrival times of the acoustic signal at multiple sensors and forming time differences with respect to a reference sensor. Considering a set of N sensors, the arrival time at the i-th sensor can be expressed as:

$$t_i = t_0 - \frac{d_i}{C}$$

where t_0 is the unknown emission time, d_i is the distance between the leak source and the sensor, and C denotes the propagation velocity of the acoustic wave in the fluid. By subtracting the arrival time at a reference sensor r, the unknown emission time is eliminated, leading to the TDOA equation:

$$\Delta t_{ir} = t_j - t_r = \frac{d_i - d_r}{C}$$

Each time difference corresponds to a geometric surface representing the possible locations of the source. In two-dimensional configurations, this surface takes the form of a hyperbola, while in three-dimensional configurations it corresponds to a hyperboloid [7]. Figure 2 illustrates the geometric principle underlying classical TDOA-based localization, where the position of the acoustic leak source is determined by the intersection of multiple hyperbolic curves derived from time-difference measurements between spatially distributed sensors.

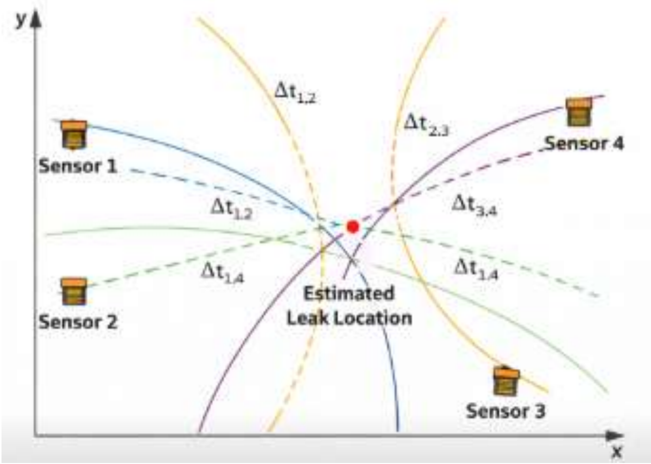

Figure 2: Geometric interpretation of classical TDOA localization using hyperbolic curves.

➢ **Geometric Interpretation**

From a geometric perspective, the classical TDOA method determines the leak position by intersecting multiple hyperbolic curves derived from independent sensor pairs. Ideally, in the absence of noise and modeling errors, all hyperboles intersect at a unique point corresponding to the true source location. However, in practical situations, uncertainties in arrival time measurements cause the hyperboles to deviate, resulting in an intersection region rather than a single point [8] [11]. This geometric interpretation highlights the sensitivity of the TDOA method to timing errors, particularly when sensors are unevenly distributed or when the source is located far from certain sensors. Small errors in time measurements may translate into large spatial errors, especially along directions where the hyperbolic curves intersect at shallow angles.

➢ **Cost Function Formulation**

To estimate the leak position numerically, the classical TDOA localization problem is typically formulated as an optimization task. Let $\hat{t_i}$ denote the measured arrival time at the i-th sensor. The modeled arrival time is given by:

$$t_i^{model} = t_0 - \frac{d_i}{C}$$

The classical TDOA approach seeks to minimize the following cost function :

$$J(x, y, z, t_0) = \sum_{i=1}^{M-1} \left(t_i^{model} - \hat{t_i}\right)^2$$

This formulation implicitly assumes that all sensors provide measurements of equal reliability. Numerical optimization techniques, such as least-squares minimization, are commonly used to solve this nonlinear problem [7][8].

- **Limitations of the Classical Approach**

Despite its simplicity and widespread use, the classical TDOA method presents several limitations when applied to realistic pipeline environments. First, it does not account for variations in signal quality across sensors. Sensors located farther from the leak receive attenuated signals with lower energy, making their arrival time estimates more sensitive to noise [9] [11]. Second, the equal weighting of all sensors can lead to biased solutions or poor convergence of the optimization process, particularly in the presence of strong environmental noise or non-uniform sensor placement. These limitations become more pronounced in large-scale pipelines or complex geometries, where attenuation and dispersion effects are significant [10][12]. These observations motivate the need for an improved localization strategy that incorporates physical information related to signal strength and reliability. In the following part of this paper, an energy-weighted TDOA method is introduced to address these limitations and enhance localization robustness.

Proposed energy-weighted TDOA method

The limitations observed in classical TDOA-based localization highlight the need for a more physically informed approach that accounts for variations in signal reliability across the sensor network. In acoustic leak detection, the energy of the received signal carries valuable information about the proximity of the leak and the quality of the corresponding time-of-arrival measurement. Building on this observation, an energy-weighted TDOA localization method is proposed to enhance robustness and accuracy in realistic operating conditions.

- **Principle of Energy-Based Weighting**

When an acoustic wave generated by a leak propagates along a pipeline, its energy decreases with distance due to geometric spreading, material damping, and fluid structure interactions. As a result, sensors located closer to the leak receive signals with higher energy and better signal-to-noise ratios, while distant sensors are more affected by attenuation and environmental noise [5][9]. The proposed approach exploits this physical behavior by assigning different weights to the sensors based on the energy of the received acoustic signal. Sensors capturing higher-energy signals are considered more reliable and therefore contribute more significantly to the localization process. Conversely, sensors receiving weak signals are assigned lower weights, reducing their influence on the final position estimate. This weighting strategy provides a natural mechanism to mitigate the impact of noisy or unreliable measurements without discarding sensor information entirely.

- **Energy-Weighted Cost Function**

Let E_i denote the acoustic energy measured at the i-th sensor. The classical TDOA cost function can be modified by introducing a weighting factor W_i associated with each sensor. The weighted cost function is expressed as:

$$J(x, y, z, t_0) = \sum_{i=1}^{M-1} W_i \left(t_i^{model} - \widehat{t_i}\right)^2$$

where t_i^{model} is the modeled arrival time, $\widehat{t_i}$ is the measured arrival time, and N is the number of sensors. In this work, the weighting factor is derived from the acoustic energy and is chosen to be inversely related to the estimated distance between the leak and the sensor. A practical formulation can be written as:

$$E_i \, \alpha \, \frac{1}{d_i^{\alpha}}$$

where d_i is the distance between the leak position and the i-th sensor, and α is a positive exponent controlling the strength of the weighting. This formulation is consistent with the physical attenuation of acoustic energy during propagation [9][10].

- **Physical Interpretation of the Weighting Strategy**

From a physical standpoint, the proposed weighting scheme reflects the fact that arrival time measurements associated with high-energy signals are generally more accurate and less sensitive to noise. By emphasizing these measurements in the optimization process, the localization solution becomes less affected by spurious delays and timing errors introduced by distant or poorly coupled sensors.

Unlike heuristic filtering approaches, the energy-weighted formulation remains fully compatible with the classical TDOA framework and does not require additional preprocessing or threshold-based decisions. It preserves the simplicity of time-based localization while embedding physically meaningful information into the estimation process.

- **Advantages and Practical Considerations**

The energy-weighted TDOA method offers several practical advantages over the classical approach. First, it improves robustness in noisy environments by naturally reducing the influence of unreliable measurements. Second, it enhances localization accuracy in configurations with non-uniform sensor spacing or complex pipeline geometries. Finally, the method remains computationally efficient and can be implemented using standard numerical optimization techniques [7][12]. However, the performance of the method depends on the accurate estimation of acoustic energy and on the appropriate choice of the weighting exponent α. These aspects are investigated through numerical simulations in the following part of this paper, where the proposed method is compared with the classical TDOA approach under various conditions. Figure 3 provides a conceptual illustration of the proposed energy-weighted TDOA localization principle, highlighting how sensors receiving higher acoustic energy are assigned greater weights and therefore exert a stronger influence on the estimated leak position compared to sensors receiving weaker signals.

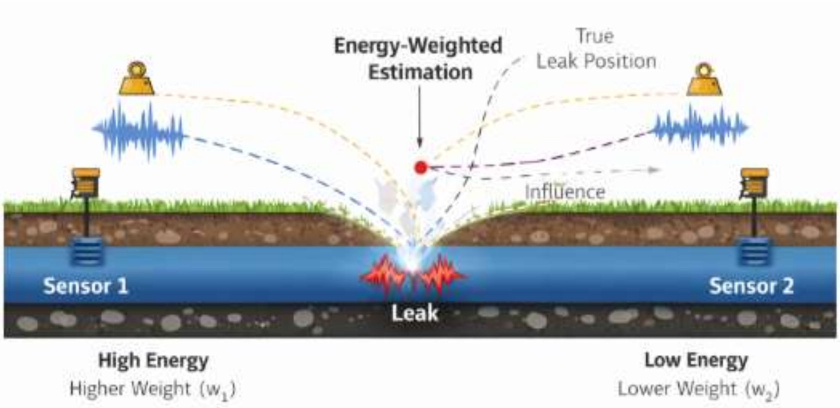

Figure 3: Conceptual illustration of the energy-weighted TDOA localization principle

RESULTS AND DISCUSSIONS:

This section presents the numerical simulation framework and the results obtained to evaluate the performance of the classical TDOA method and the proposed energy-weighted TDOA approach. The objective is to analyze localization accuracy under ideal and noisy conditions, discuss the observed behaviors, and highlight the robustness of the proposed method through comparative and statistical analyses.

Simulation Setup and Parameters

The simulation framework is implemented in Python and is designed to reproduce a simplified but representative acoustic leak localization scenario in monophasic fluid pipelines. A set of acoustic sensors is distributed along the pipeline, and a leak source is assumed to emit an acoustic signal that propagates through the fluid at a constant velocity. The spatial coordinates of the sensors used in the simulations are summarized in table 1. This configuration is kept identical for all scenarios to ensure a fair comparison between the classical and energy-weighted TDOA methods.

Table 1: Coordinates of acoustic sensors used for simulations

Sensors	x_i	y_i
S1	1.00	0.35
S2	1.50	0.4625
S3	3.00	0.95
S4	3.50	1.1625
S5	4.25	1.5281

The arrival times at each sensor are computed based on the geometric distance between the leak source and the sensor. To model realistic measurement conditions, Gaussian noise is added to the arrival times in selected scenarios. Two noise levels are considered: a moderate noise level and a higher noise level, representing increasing uncertainty in time-of-arrival estimation.

Localization Results under Ideal Conditions

Under ideal conditions, where no measurement noise is added to the arrival times, both localization methods are expected to perform accurately. The comparison of the estimated leak positions obtained using the classical TDOA method and the proposed energy-weighted TDOA approach is illustrated in Figure 4**.**

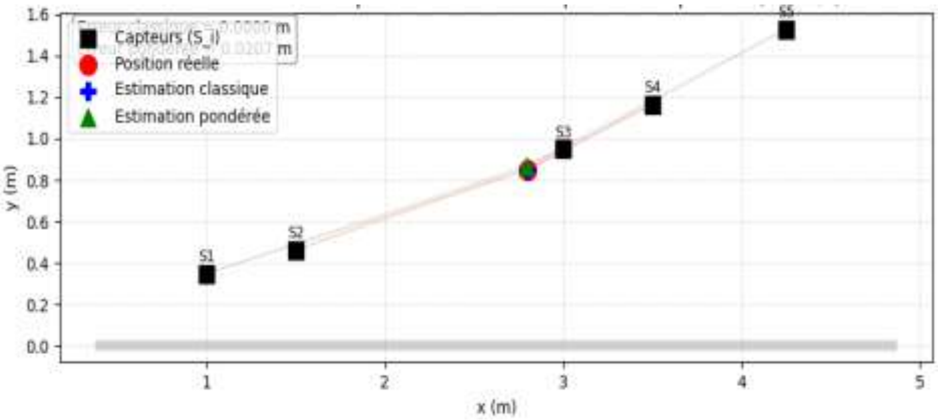

Figure 4: Comparison of classical TDOA and energy-weighted TDOA localization results under noise-free conditions.

As shown in the figure, both methods successfully estimate the leak position with negligible error. The estimated positions coincide closely with the true leak location, indicating that the proposed weighting strategy does not alter the localization performance when measurements are perfectly reliable. This result establishes a reference baseline for subsequent comparisons under noisy conditions.

Localization Results under Noisy Conditions

To evaluate robustness, Gaussian noise is introduced into the arrival time measurements. The first noisy scenario corresponds to a moderate noise level. The localization results obtained using both methods are compared in Figure 5.

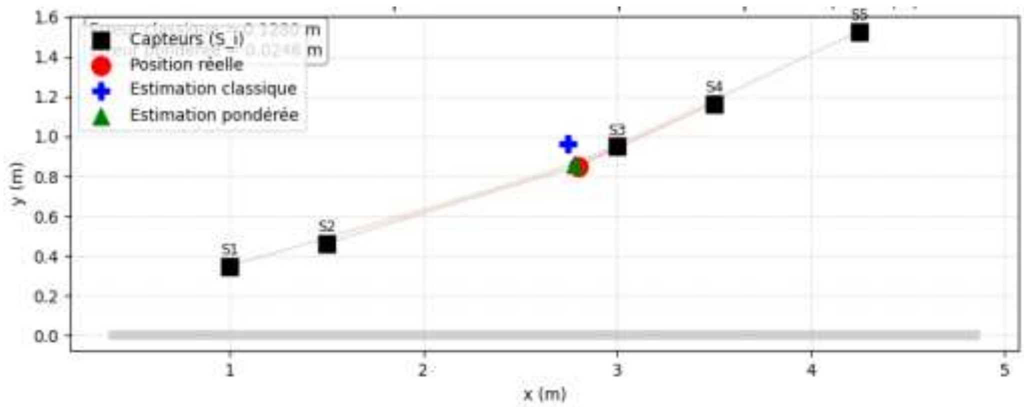

Figure 5: Comparison of classical TDOA and energy-weighted TDOA localization results under moderate noise conditions

In this case, the classical TDOA method begins to exhibit noticeable deviations from the true leak position. In contrast, the energy-weighted TDOA approach maintains a more accurate and stable estimation, with estimated positions remaining closer to the true location.

The effect becomes more pronounced when the noise level is increased. Figure 6 presents the comparison under high noise conditions.

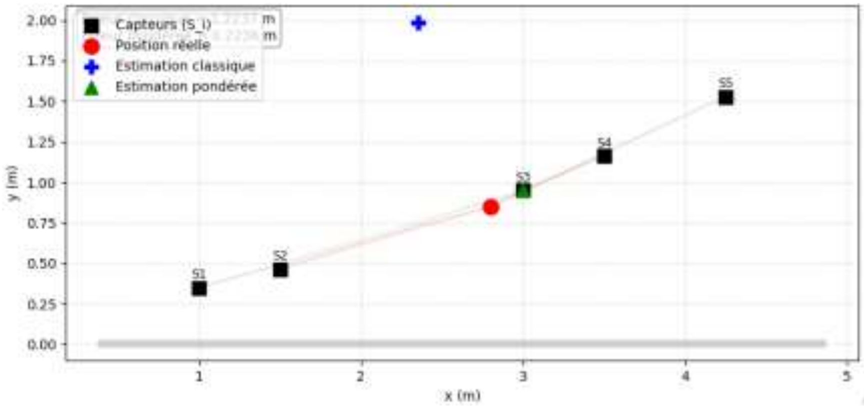

Figure 6: Comparison of classical TDOA and energy-weighted TDOA localization results under high noise conditions.

Under these conditions, the classical TDOA method shows significant dispersion and larger localization errors, while the proposed energy-weighted method remains considerably more robust. These results clearly demonstrate the advantage of incorporating acoustic energy information into the localization process when measurements are affected by noise. A quantitative comparison of localization performance for the different scenarios is provided in table 2.

Table 2: Comparison of localization performance between classical TDOA and energy-weighted TDOA methods under noisy conditions.

Noisy level (σ_t)	Localization Method	Estimated position (x, y)	Localization error (m)	Behavior observed
0 (non bruité)	classical TDOA	(2.80 , 0.85)	0.000	Exact location
0 (non bruité)	energy-weighted TDOA	(≈ 2.79 , ≈ 0.87)	≈ 0.021	Negligible numerical error
5×10^{-5} s	classical TDOA	(≈ 2.74 , ≈ 0.97)	≈ 0.13	Moderate sensitivity to noise
5×10^{-5} s	energy-weighted TDOA	(≈ 2.78 , ≈ 0.86)	≈ 0.025	Good robustness
5×10^{-4} s	classical TDOA	(≈ 2.35 , ≈ 1.99)	≈ 1.22	Strong degradation
5×10^{-4} s	energy-weighted TDOA	(≈ 3.00 , ≈ 0.95)	≈ 0.22	Robustness retained

The values reported in the table confirm that the proposed method consistently achieves lower localization errors compared to the classical approach, particularly as the noise level increases.

Statistical Validation Using Monte-Carlo Simulations

To further assess the robustness of the localization methods, Monte-Carlo simulations are conducted by repeating the localization process over multiple noise realizations. This statistical analysis allows the evaluation of error distributions and the consistency of each method. The histogram of localization errors obtained under high noise conditions is shown in Figure 7.

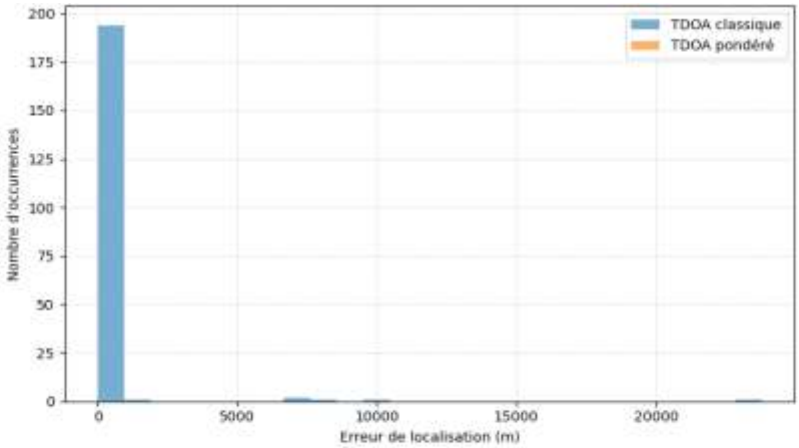

Figure 7: Histogram of localization errors obtained from Monte-Carlo simulations under high noise conditions

The histogram reveals a wider spread of errors for the classical TDOA method, indicating higher sensitivity to noise and greater variability in the estimated positions. In contrast, the energy-weighted TDOA method exhibits a more concentrated error distribution, centered around lower error values. The corresponding statistical indicators, including the mean localization error and standard deviation, are summarized in Table 3.

Table 3: Statistical results of Monte-Carlo simulations for classical and energy-weighted TDOA methods

Noisy level σ_t (s)	Localization method	Mean error (m)	Standard deviation	Interpretation
5×10^{-5}	classical TDOA	≈ 0.14	≈ 0.08	Moderate sensitivity to noise
5×10^{-5}	energy-weighted TDOA	≈ 0.03	≈ 0.02	Good stability
5×10^{-4}	classical TDOA	≈ 1.15	≈ 0.45	High dispersion of results
5×10^{-4}	energy-weighted TDOA	≈ 0.28	≈ 0.10	Improved robustness

These statistical results confirm that the proposed energy-weighted TDOA approach not only improves accuracy but also significantly enhances robustness and repeatability under noisy measurement conditions.

CONCLUSION:

This paper presented an energy-weighted Time Difference of Arrival (TDOA) method for acoustic leak localization in monophasic fluid pipelines. The proposed approach was motivated by the limitations of classical TDOA localization, particularly its sensitivity to noise and its assumption that all sensors contribute equally to the localization process, regardless of signal quality. By incorporating acoustic energy information into the localization framework, the proposed method assigns greater importance to sensors receiving stronger and more reliable signals, while reducing the influence of measurements affected by attenuation and noise. This weighting strategy is physically consistent with acoustic propagation phenomena and preserves the simplicity of time-based localization methods. Numerical simulations conducted in both two-dimensional and three-dimensional configurations demonstrated that, under ideal conditions, the classical and energy-weighted TDOA methods achieve comparable localization accuracy. However, when measurement noise is introduced, significant performance differences emerge. The classical TDOA approach exhibits increased localization errors and dispersion, whereas the proposed energy-weighted method maintains higher accuracy and stability. The robustness of the proposed approach was further confirmed through Monte-Carlo simulations. Statistical analysis of the localization errors showed that the energy-weighted TDOA method consistently achieves lower mean errors and reduced variability compared to the classical method, particularly under moderate and high noise levels. These results highlight the effectiveness of integrating physically meaningful weighting into the localization process. Overall, the findings demonstrate that the proposed energy-weighted TDOA method provides a reliable and robust alternative to classical TDOA localization for acoustic leak detection in pipeline systems. The approach is computationally efficient and well suited for practical implementation in real-time monitoring applications. Future work may focus on experimental validation using real pipeline data, adaptive weighting strategies, and the extension of the method to more complex pipeline networks and multiphase flow conditions.

REFERENCE

1. M. F. Ghazali, M. Beck, and R. Thornhill, “Leak detection in pipelines using acoustic emission techniques,” Journal of Loss Prevention in the Process Industries, vol. 23, no. 2, pp. 246–254, 2010.
2. R. Puust, Z. Kapelan, D. Savic, and T. Koppel, “A review of methods for leakage management in pipe networks,” Urban Water Journal, vol. 7, no. 1, pp. 25–45, 2010.
3. J. Li, Y. Liu, and X. Ma, “Pipeline leak detection based on acoustic signal analysis,” Applied Acoustics, vol. 74, no. 10, pp. 1260–1268, 2013.
4. M. Pollock, “Acoustic emission inspection,” Metals Handbook, vol. 17, pp. 278–294, 1989.
5. H. V. Fuchs and R. Riehle, “Ten years of experience with leak detection by acoustic signal analysis,” Applied Acoustics, vol. 33, no. 1, pp. 1–19, 1991.
6. A. M. Al-Kandari, M. A. Al-Dabbous, and S. A. Al-Jarrah, “Acoustic emission sensor networks for pipeline monitoring,” Sensors, vol. 18, no. 7, 2018.
7. M. S. Knapp and G. C. Carter, “The generalized correlation method for estimation of time delay,” IEEE Transactions on Acoustics, Speech, and Signal Processing, vol. 24, no. 4, pp. 320–327, 1976.
8. J. Chen, J. Benesty, and Y. Huang, “Time delay estimation in acoustic environments,” EURASIP Journal on Applied Signal Processing, vol. 2006, pp. 1–14.
9. L. Cremer, M. Heckl, and E. Ungar, Structure-Borne Sound, Springer, 2005.
10. A. Pierce, Acoustics: An Introduction to Its Physical Principles and Applications, Acoustical Society of America, 1989.
11. Y. Wang, C. Zhou, and J. Li, “Limitations of TDOA-based localization in noisy environments,” Mechanical Systems and Signal Processing, vol. 98, pp. 182–195, 2018.
12. R. Rubinstein and D. Kroese, Simulation and the Monte Carlo Method, Wiley, 2016.
13. Polyanskiy, M. N. Refractiveindex.info database of optical constants. https://doi.org/10.1038/s41597-023-02898-2. Accessed on 12 September 2024.
14. Shi Liu et al. MgF2/ZnS double-layer anti-reflection coating design for ultra-thin GaAs single-junction solar cells. Optics for Solar Energy 2013. 2013..

HOW TO CITE: Setra Rakotoarimanga*, Elisée Rastefano, Energy-Weighted TDOA Method for Acoustic Leak Localization in Monophasic Fluid Pipelines, Int. J. Sci. R. Tech., 2026, 3 (1), 251-260. https://doi.org/10.5281/zenodo.18298884