ISSN: 3066-7194
Review Article

Novel Journal of Applied Sciences Research

Decoding Signal Dynamics: Unveiling the Essence of Signal Analysis

Walid Mohamedi

Cadi Ayed University

***Corresponding author:** Walid Mohamedi, Cadi Ayed University.

Submitted: 05 February 2024 **Accepted:** 12 February 2024 **Published:** 18 March 2024

https://doi.org/10.63620/MKNJASR.2024.1006

Citation: *Mohamedi, W. (2024). Decoding Signal Dynamics: Unveiling the Essence of Signal Analysis. Nov Joun of Appl Sci Res, 1(2), 01-06.*

Abstract

Signal analysis stands as a pivotal cornerstone, intricately woven into the fabric of diverse scientific, engineering, and technological realms. Its significance transcends disciplines, providing invaluable insights that unravel the distinctive characteristics inherent in a myriad of signals. Central to this analysis are three fundamental metrics—mean frequency, power, and bandwidth. In the following discourse, this article embarks on a journey to illuminate the profound significance encapsulated within these parameters, peeling back the layers to uncover their importance. Through a meticulous exploration, we delve into the methodologies meticulously employed for the precise measurement of mean frequency, power, and bandwidth, unraveling the intricate tapestry of signal analysis.

Introduction

Vibration analysis is a sophisticated and widely employed methodology for studying the dynamic behavior of mechanical systems, structures, and machinery. This powerful diagnostic tool involves the comprehensive examination of oscillatory motion and the interpretation of resulting vibration signals to gain valuable insights into the health and performance of a system. By harnessing principles from physics, engineering, and signal processing, vibration analysis serves as a cornerstone in predictive maintenance, condition monitoring, and fault diagnosis across various industries [1-12].

The primary goal of vibration analysis is to discern and interpret the intricate patterns of motion within a system, translating them into meaningful information about its condition. Through the use of specialized sensors and sophisticated analytical techniques, practitioners can extract valuable data regarding frequency, amplitude, and phase, unveiling the vibrational characteristics that hold key diagnostic clues [13-29].

This methodology plays a crucial role in preventing unexpected breakdowns, optimizing maintenance schedules, and extending the lifespan of machinery and structural components. As industries increasingly rely on advanced technologies, the role of vibration analysis becomes even more significant, contributing to improved reliability, efficiency, and safety in a diverse range of applications [30-47].

In this exploration of vibration analysis, we delve into the fundamental principles, methodologies, and applications that make it an indispensable tool for engineers, maintenance professionals, and researchers seeking to understand, monitor, and enhance the performance of dynamic systems [48-63].

In the intricate realms of scientific, engineering, and technological pursuits, the art of signal analysis takes center stage, bestowing invaluable insights into the unique characteristics of diverse signals. Amidst the fundamental parameters awaiting meticulous examination, mean frequency, power, and bandwidth emerge as cardinal metrics. This article embarks on a journey to unravel the profound significance encapsulated within these parameters, offering a comprehensive exploration of their importance and the methodologies intricately woven into their precise measurement.

The Occupied Bandwidth

Mean frequency is a fundamental parameter that reveals the central tendency of a signal's frequency content. It represents the average frequency at which the signal's energy is distributed. In signal processing, determining the mean frequency is essential for understanding the dominant spectral components. Common methods for calculating mean frequency include Fourier analysis and wavelet transforms. Engineers and researchers often leverage mean frequency to identify the central frequency around which other spectral components are distributed.

The occupied bandwidth is a measure of the range of frequencies that contain a certain percentage of the signal's power. In this case, you're asked to estimate the bandwidth that contains 99% of the signal's power.

This involves analyzing the power spectral density (PSD) plot and identifying the frequency range where 99% of the total power is encompassed. This can be done by integrating the area under the PSD curve and determining the frequency limits that correspond to 99% of this area (see figure 1).

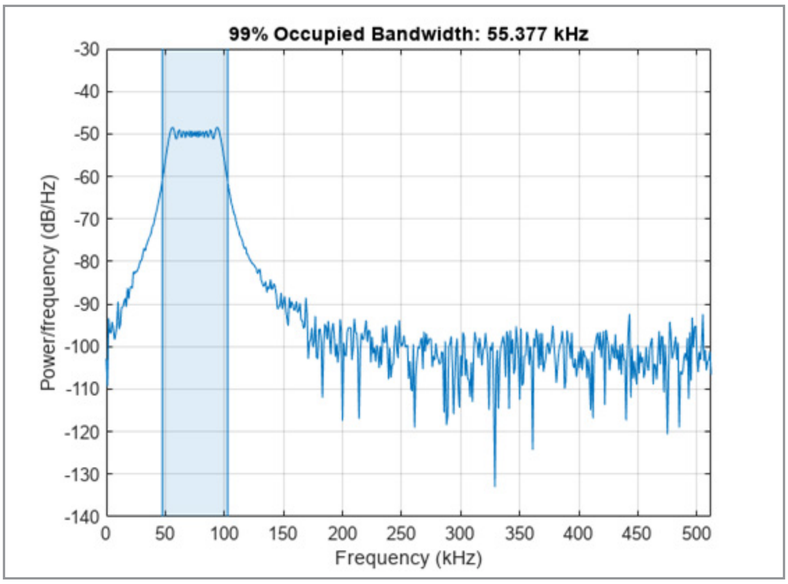

Figure 1: Power /frequency as a function of frequency

In general terms, the power spectral density is the Fourier transform of the autocorrelation function of a signal. It provides information about the distribution of power with respect to frequency.

The power spectral density is commonly plotted on a graph where the x-axis represents frequency, and the y-axis represents the power or power density. This graph visually illustrates how the power of a signal is distributed across different frequency components.

So, when someone mentions "power/frequency as a function of frequency," they are likely referring to a graph or plot where the power (or power density) is shown as a function of frequency, providing insights into the frequency content of a signal.

Generate another chirp. Specify an initial frequency of 200 kHz, a final frequency of 300 kHz, and an amplitude that is twice that of the first signal. Add white Gaussian noise.

Combine the two chirp signals to generate a composite signal. Proceed to calculate the Power Spectral Density (PSD) of this combined signal, providing insights into its frequency distribution. Subsequently, create a graphical representation of the PSD, with the x-axis denoting frequency and the y-axis indicating power or power density. Finally, mark or annotate the median frequency on the PSD plot, illustrating the central frequency point around which the signal's power is evenly distributed.

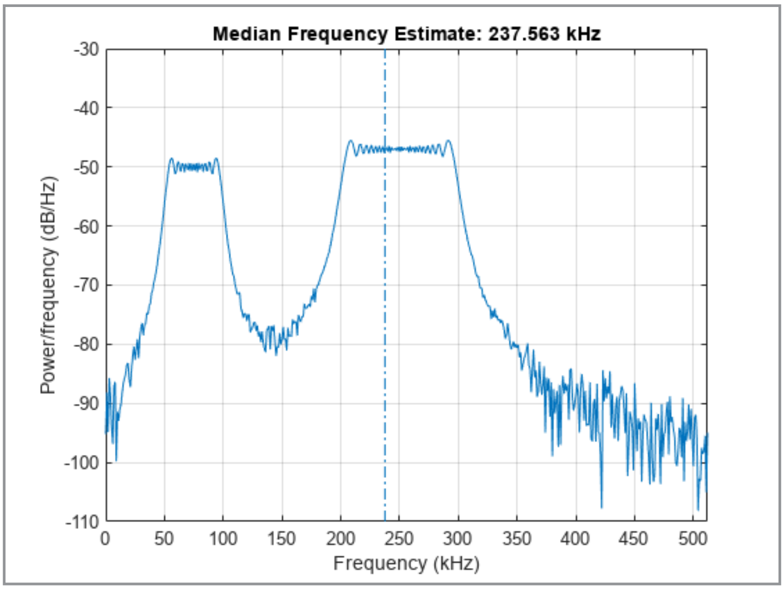

Figure 2 : Median frequency on the PSD

Generate a Power Spectral Density (PSD) plot and mark or annotate the mean frequency on the graph.

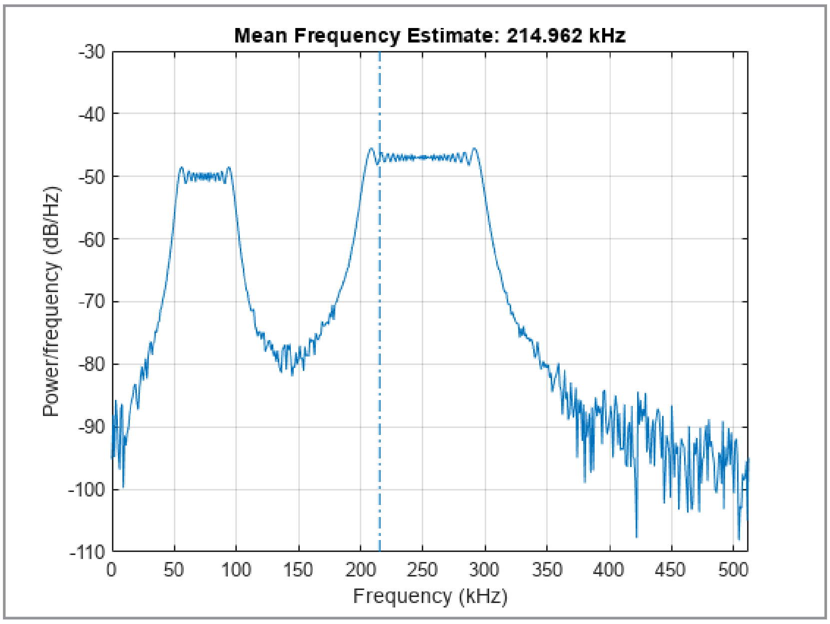

Figure 3: Mean frequency on the PSD

Chirp-Based Channel Analysis

The given statement suggests a signal processing task where chirps, which are signals with varying frequencies over time, are treated as distinct channels. The objective is to analyze these channels individually, estimating the mean frequency for each and visually presenting the results on a plot of Power Spectral Densities (PSDs). In signal processing, a "chirp" is a signal characterized by a frequency that changes with time. By considering each chirp as a separate channel, we treat them as distinct components or sources within the overall signal.

The task involves determining the average or mean frequency for each identified chirp or channel. This can be achieved through various techniques, such as analyzing the frequency content of the signal and calculating a central frequency representative of each channel.

PSD is a tool used to visualize the distribution of a signal's power across different frequencies. Creating a plot of PSDs involves representing the power content of each chirp or channel as a function of frequency. After estimating the mean frequency for each channel, the next step is to annotate the plot of PSDs. This annotation includes marking or labeling the plot to indicate the mean frequency associated with each channel. This step enhances the interpretability of the plot by highlighting key frequency characteristics (see Figure 4).

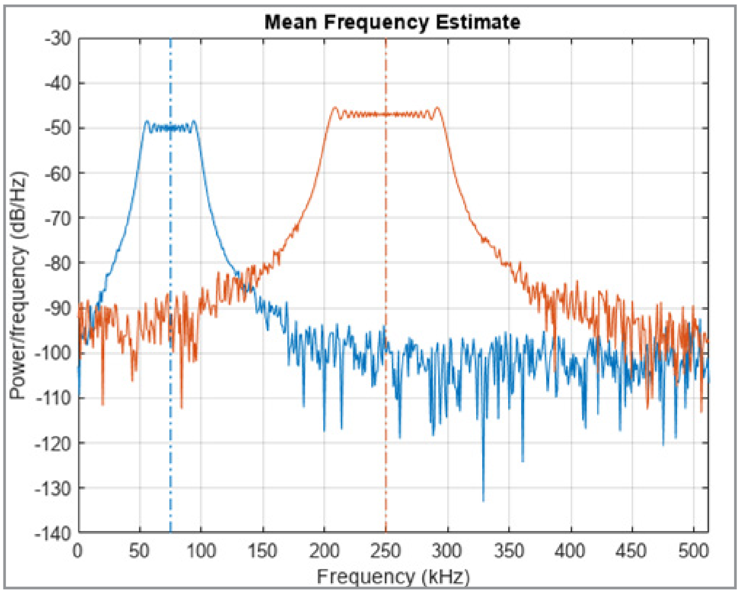

Figure 4: The curve of Chirp-Based Channel Analysis

In practical terms, this process allows for a detailed exploration of the frequency components within each chirp, offering insights into the dominant frequencies and their variations across different channels. The annotated plot serves as a visual representation of the distribution of mean frequencies, aiding in the analysis and interpretation of the signal's characteristics. This approach is valuable in various fields, including telecommunications, audio processing, and vibration analysis, where understanding frequency components is crucial.

Power Measurement: Quantifying Signal Strength

Power is a crucial metric in signal analysis, quantifying the strength or intensity of a signal. It provides information about the signal's energy content and is fundamental for assessing its amplitude. Power measurement is particularly significant in fields such as telecommunications, audio processing, and vibration analysis. In the context of power spectral density, it helps identify frequency regions where the signal carries significant energy. Power measurement methods include time-domain techniques, such as root mean square (RMS), and frequency-domain methods, like Parseval's theorem in Fourier analysis.

Bandwidth characterizes the range of frequencies occupied by a signal and is another vital parameter in signal analysis. It is defined as the difference between the upper and lower frequencies within which the signal's power is significant. The bandwidth provides insights into the signal's capacity to carry information and is crucial in communication systems, where efficient use of available frequency bands is essential. Bandwidth measurement methods depend on the type of signal but often involve determining the frequency range containing a specified percentage of the signal's power.

Conclusion

In conclusion, mean frequency, power, and bandwidth are fundamental parameters in signal analysis, offering valuable insights into the characteristics of diverse signals. Whether in telecommunications, audio processing, vibration analysis, or biomedical signal processing, accurate measurement of these parameters enhances our understanding of signals and facilitates informed decision-making in various applications. Researchers and practitioners continue to advance methodologies for precise and efficient measurement, contributing to the evolving landscape of signal analysis.

Reference

1. Reguieg, S. K., Ghemari, Z., & Benslimane, T. (2018). Extraction of the relative sensitivity model and improvement of the piezoelectric accelerometer performances. 2018 International Conference on Signal, Image, Vision and their Applications (SIVA).
2. Ghemari, Z., & Saad, S. (2019). The use of mechanical sensitivity model to enhance capacitive sensor characteristics. Analog Integrated Circuits and Signal Processing, 99, 349-357.
3. Ghemari, Z., & Saad, S. (2019). Enhancement of capacitive accelerometer operation by parameters improvement. International Journal of Numerical Modelling Electronic Networks Devices and Fields, 32, e2568.
4. Ghemari, Z., Saad, S., & Defdaf, M. (2021). Appropriate Choice of Damping Rate and Frequency Margin for Improvement of the Piezoelectric Sensor Measurement Accuracy. Journal of Advanced Manufacturing Systems, 20, 537-548.
5. He, Y., Liu, J., Wu, S., & Wang, X. (2023). Condition Monitoring and Fault Detection of Wind Turbine Driveline With the Implementation of Deep Residual Long Short-Term Memory Network. IEEE Sensors Journal, 23, 13360-13376.
6. Kavil Kambrath, J., Khan, M. S. U., Wang, Y., Maswood, A. I., & Yoon, Y. J. (2019). A Novel Control Technique to Reduce the Effects of Torsional Interaction in Wind Turbine System. IEEE Journal of Emerging and Selected Topics in Power Electronics, 7, 2090-2105.
7. Kambrath, J. K., Changwoo, Y., Wang, Y., & Yoon, Y. J. (2018). Modelling and Control to Mitigate Dynamic Effects of Unbalanced Masses in Wind Turbine Systems. 2018 IEEE Energy Conversion Congress and Exposition (ECCE), 408-415.
8. Ting, H., Daoshan, H., Yan, L., Zhenhua, X., Weijun, Z., & Yan, L. (2019). Study on Regional Power Grid Stability of Large Scale Wind Power Based on Wind Farm Detailed Model. 2019 IEEE 3rd Advanced Information Management, Communicates, Electronic and Automation Control Conference (IMCEC), 530-534.
9. Schkoda, R. F. (2015). Static uncertainty analysis of a wind turbine test bench's load application unit. 2015 American Control Conference (ACC), 3150-3155.
10. Ghemari, Z., & Saad, S. (2017). Parameters improvement and suggestion of new design of capacitive accelerometer'' Analog Integrated Circuits and Signal Processing, 92, 443-451.
11. Ghemari, Z., Saad, S., Amrouche, A., & Lakehal, A. (2015). New model of piezoelectric accelerometer relative movement modulus'' Transactions of the Institute of Measurement and Control, 37, 932-941.
12. Ghemari, Z., & Saad, S. (2013). Modeling and enhancement of mechanical sensitivity of vibration sensor. Journal of Vibration and Control, 20, 2234-2240.
13. Ghemari, Z., Chouaf, F., & Saad, S. (2017). New Formula for the Piezoresistive Accelerometer Motion Acceleration and Experimental Validation. Journal of Advanced Manufacturing Systems, 16, 57-65.
14. Ghemari, Z., & Lakehal, A. (2015). Minimisation of resonance phenomena effect of piezoresistive accelerometer. 2015 4th International Conference on Systems and Control (ICSC), 243-246.
15. Ghemari, Z., & Saad, S. (2013). Improvement of piezoresistive accelerometer performance. 3rd International Conference on Systems and Control, 759-762.
16. Chen, S., Ding, S., Shen, S., Dai, Y., Yang, Z., & Zhang, J. (2021). Influence of Field Weakening Control on Electromagnetic Force and Electromagnetic Vibration of SPMSMs. 2021 IEEE 12th Energy Conversion Congress & Exposition - Asia (ECCE-Asia), 221-225.
17. Chen, T., Zhong, X., Li, Z., & Hu, F. (2021). Analysis of Intermolecular Weak Interactions and Vibrational Characteristics for Vanillin and Ortho-Vanillin by Terahertz Spectroscopy and Density Functional Theory. IEEE Transactions on Terahertz Science and Technology, 11, 318-329.
18. Li, X., Hao, J., Liu, Q., Gong, R., Jiang, X., & Ding, Y. (2022). Study on Mechanical Vibration Characteristics of GIS Equipment under Variable Frequency Currents. 2022

IEEE International Conference on High Voltage Engineering and Applications (ICHVE), 1-4.
19. Qiu, F. (2023). Analysis on Vibration and Noise Characteristics of Epoxy Resin Dry-Type Transformer and Noise Reduction Measures. 2023 IEEE 4th International Conference on Electrical Materials and Power Equipment (ICEMPE), 1-4.
20. Ghemari, Z. (2018). Analysis and optimization of vibration sensor. IEEE International Conference on Smart Materials and Spectroscopy (SMS'2018).
21. Ghemari, Z. (2016). Upgrading of piezoresistive accelerometer response. 2016 8th International Conference on Modelling, Identification and Control (ICMIC).
22. Ghemari, Z., & Saad, S. (2014). Reducing the Measurement Error to Optimize the Sensitivity of the Vibration Sensor. IEEE Sensors Journal, 14, 1527-1532.
23. Ghemari, Z., & Saad, S. (2019). Defects diagnosis by vibration analysis and improvement of vibration sensor measurement accuracy. Sensor Letters, 17, 608-613.
24. Ghemari, Z. (2018). Decrease of the resonance phenomenon effect and progress of the piezoelectric sensor correctness. 2018 International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM).
25. Ghemari, Z., & Saad, S. (2017). Simulation and Experimental Validation of New Model for the Piezoresistive Accelerometer Displacement. Sensor Letters, 15, 02.
26. Lakehal, A., & Ghemari, Z. (2016). Suggestion for a new design of the piezoresistive accelerometer. Ferroelectrics, 493, 93-102.
27. Saad, S., Ghemari, Z., Herous, L., & Hadjadj, O. E. (2007). Transducer (Accelerometer) Modeling and Simulation. Asian Journal of Information Technology, 6, 54-57.
28. Chen, X. (2023). Investigation of the Core's Vibration Characteristics of a Distribution Transformer. 2023 International Conference on Power Energy Systems and Applications (ICoPESA), 707-711.
29. Gao, B., Wang, C., Ren, L., & Chen, P. (2023). Vibration Characteristics Analysis of Transformer Core Faults Based on Multy-Physical Field Coupling. 2023 IEEE International Conference on Mechatronics and Automation (ICMA), 731-736.
30. Santhanakrishnan, T., Devassy, H., & Chandrakanta, A. S. (2020). Exploiting the non-uniform characteristics of Silicon photodiode in vibration monitoring. 2020 IEEE 4th Conference on Information & Communication Technology (CICT), 1-6.
31. Cao, J., & Zhang, Z. (2018). Identification of bonding strength for explosive clad pipe utilizing vibration characteristics. 2018 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), 1-6.
32. Zeitler, J. A. (2018). Using Low-Frequency Vibrational Dynamics to Probe Disorder in Organic Molecular Materials. 2018 43rd International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz), 1-3.
33. Ghemari, Z., & Lakehal, A. (2014). Vibration sensor mechanical sensitivity improvement. International Conference on Electrical Sciences and Technologies in Maghreb.
34. Ghemari, Z. (2013). Modélisation, simulation et analyse expérimentale du capteur de vibration (accéléromètre). Thèse de doctorat, Université de M'sila.
35. Ghemari, Z., Belkhiri, S., & Saad, S. (2023). Improvement of the relative sensitivity for obtaining a high performance piezoelectric sensor. IEEE Instrumentation & Measurement Magazine, 26, 49-56.
36. Lakehal, A., & Ghemari, Z. (2015). Proposition d'une nouvelle formule d'accélération du mouvement pour l'accéléromètre. 3ème Conférence Internationale sur la Maintenance et la Sécurité Industrielle.
37. Ding, Y., Zhong, Y., Wang, X., Hao, J., & Jiang, X. (2021). Difference and Analysis of Mechanical Vibration Signal Characteristics between Mechanical Defects and Partial Discharge Defects of Gas Insulated Switchgear. 2021 IEEE 5th International Conference on Condition Assessment Techniques in Electrical Systems (CATCON), 211-214.
38. Sandhu, M. M., Geissdoerfer, K., Khalifa, S., Jurdak, R., Portmann, M., & Kusy, B. (2020). Towards Optimal Kinetic Energy Harvesting for the Batteryless IoT. 2020 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops), 1-6.
39. Shen, Y., Zhang, X., Jiang, H., Zhou, J., Qiao, S., et al. (2020). Comparative Study on Dynamic Characteristics of Two-Stage Gear System with Gear and Shaft Cracks Considering the Shaft Flexibility. IEEE Access, 8, 133681-133699.
40. Li, D., Yu, Z., Zhao, J., & Zhang, L. (2019). Study on axial vibration characteristics of transformer winding. 2019 14th IEEE Conference on Industrial Electronics and Applications (ICIEA), 1080-1083.
41. Ghemari, Z., & Belkhiri, S. (2021). Capacitive Sensor Accuracy Optimisation by the Frequency Range Appropriate Choice. Preprint.
42. Ghemari, Z. (2019). Enhancement of the vibratory analysis technique by the accelerometer characteristics evolution. The 7th International Conference on Control Engineering & Information Technology.
43. Ghemari, Z., Belkhiri, S., & Saad, S. (2023). A capacitive sensor with high measurement accuracy and low electrical energy consumption. Applied Physics A, 129, 362.
44. Ghemari, Z., Belkhiri, S., & Morakchi, M. R. (2022). Improvement of the vibration analysis technique by optimizing the parameters of the piezoelectric accelerometer. 2022 IEEE 21st international Ccnference on Sciences and Techniques of Automatic Control and Computer Engineering (STA), 183-186.
45. Ghemari, Z., Belkhiri, S., & Saad, S. (2023). A piezoelectric sensor with high accuracy and reduced measurement error. Preprint in Research Square.
46. Bonde, A., Pan, S., Mirshekari, M., Ruiz, C., Noh, H. Y., & Zhang, P. (2020). OAC: Overlapping Office Activity Classification through IoT-Sensed Structural Vibration. 2020 IEEE/ACM Fifth International Conference on Internet-of-Things Design and Implementation (IOTDI), 216-222.
47. Zhao, X., Wang, Y., Cheng, H., Guo, J., Xu, Q., & Hao, J. (2022). Experimental Study on the Influence of Vibration Frequency on Gas Production Characteristics of Oil-paper Insulation. 2022 IEEE International Conference on High Voltage Engineering and Applications (ICHVE), 1-4.
48. Zhao, X., Yao, C., Zhou, Z., Li, C., Wang, X., et al. (2019). Experimental Evaluation of Transformer Internal Fault De-

tection Based on V–I Characteristics. IEEE Transactions on Industrial Electronics, 67, 4108-4119.

49. Li, S., Tong, X., Huang, J., Wu, X., Yang, W., & Pan, Z. (2020). A Thermal and Vibrational Feedback Glove Based on the Tactile Characteristics of Human Hand Skin. IEEE Access, 8, 226671-226684.
50. Ghemari, Z., Belkhiri, S., & Saad, S. (2023). Appropriate choice of Capacitive sensor bandwidth. Preprint in Research Square.
51. Belkhiri, S., Ghemari, Z., & Saad, S. (2022). Reduction of measurement error of the piezoelectric sensor. Séminaire International en Génie Industriel et Mathématiques Appliquées (SIGIMA'2022).
52. Aissaoui, L., & Ghemari, Z. (2022). Mathematical modeling and simulation of the piezoelectric accelerometer. 3rd International Conference on Applied Engineering and Natural Sciences.
53. Morakchi, M. R., GHEMARI, Z., DEFDAF, M., merwane, k., selman, d., & Lina, A. (2022). Different MEMS-based accelerometers types. 3rd International Conference on Applied Engineering and Natural Sciences.
54. Wu, S., Zhang, Q., Xu, H., Gan, D., & He, G. (2021). Oscillatory Stability Analysis for Power Systems with High Penetration of Photovoltaic Generation: The Minimum Characteristic-Locus Method. 2021 International Conference on Power System Technology (POWERCON), 971-979.
55. Zhong, Y., Hao, J., Ding, Y., Liao, R., Xu, H., & Li, X. (2022). Novel GIS Mechanical Defect Simulation and Detection Method Based on Large Current Excitation with Variable Frequency. IEEE Transactions on Instrumentation and Measurement, 71, 1-15.
56. Fu, Y., Gui, H., Li, W., & Wang, Z. (2020). Virtual Material Modeling and Vibration Reduction Design of Electron Beam Imaging System. 2020 IEEE International Conference on Advances in Electrical Engineering and Computer Applications (AEECA), 1063-1070.
57. Ghemari, Z. (2019). The accelerometer characteristics improvement. The 7th International Conference on Control Engineering & Information Technology.
58. Morakchi, M. R., GHEMARI, Z., DEFDAF, M., Guezi, A., Selman, d., & Merwane, K. (2022). MEMS accelerometer and gyroscope in navigation technology. 3rd International Conference on Applied Engineering and Natural Sciences.
59. Morakchi, M. R., & Ghemari, Z. (2022). The best choice of the capacitive accelerometer damping rate for reduction of the measurement error. La 1ere conférence internationale d'Electrotechnique et Technologies Modernes CIETM'22.
60. Morakchi, R., Ghemari, Z., & Defdaf, M. (2022). The optimal accelerometer parameter integrated into the mathematical model for avoiding detection errors. 1st International Conference on Engineering and Applied Natural Sciences.
61. Ghemari, Z., & Saad, S. (2019). The use of mechanical sensitivity model to enhance capacitive sensor characteristics. Analog Integrated Circuits and Signal Processing, 99, 349-357.
62. Ghemari, Z. (2018). Improvement of the piezoelectric sensor by the progress of the measurement accuracy" IEEE International Conference on Smart Materials and Spectroscopy (SMS'2018).
63. Ghemari, Z., & Saad, S. (2019). Enhancement of capacitive accelerometer operation by parameters improvement. International Journal of Numerical Modelling Electronic Networks Devices and Fields, 32, e2568.