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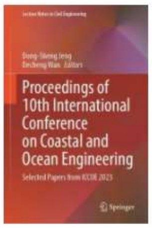

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Design of a Scalogram-Based Data Acquisition and Processing System for a Multi-sensor Network Application for Marine Structures

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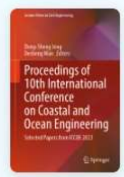

Proceedings of 10th International Conference on Coastal and Ocean Engineering

(ICCOE 2023)

Xuan-Phuong Nguyen, Xuan-Kien Dang ✉, Le Anh-Hoang Ho, Hoang-Minh Luu & Ngoc-Truc Nguyen

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Abstract
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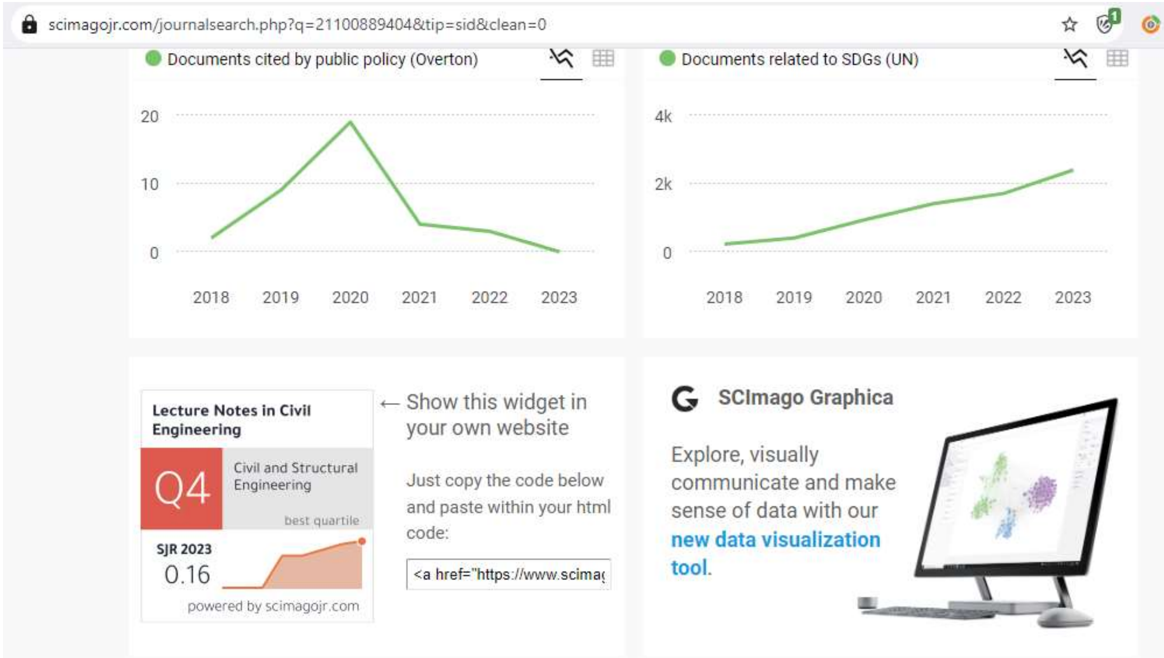
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Abstract	Offshore maritime structural systems must be monitored for safety concerns to provide warnings and perform maintenance and repair work on schedule. Because marine structures are usually affected by a variety of factors, including earthquakes and environmental aspects, this activity is crucial (waves, wind, and currents). The purpose of early structural damage detection is to avoid significant damage that might lead to loss of life or property. Besides, with the support of a multipoint sensor network, we develop a data collection and processing system in this study, and we investigate how to extract scalogram images from the wavelet transform of the signals the sensor sends out to evaluate the state of the Offshore Jacket Platform structure. The efficiency of the proposed strategy has been demonstrated using an embedded model in MATLAB running on the STM32 NucleoF411RE central processor that collects vibration signals from the accelerometer through an Offshore Jacket Platform-installed multi-sensor network.

Keywords (separated by '-')	Multipoint Sensor Network - Offshore Jacket Platform - Wavelet Transform

Design of a Scalogram-Based Data Acquisition and Processing System for a Multi-sensor Network Application for Marine Structures

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Abstract. Offshore maritime structural systems must be monitored for safety concerns to provide warnings and perform maintenance and repair work on schedule. Because marine structures are usually affected by a variety of factors, including earthquakes and environmental aspects, this activity is crucial (waves, wind, and currents). The purpose of early structural damage detection is to avoid significant damage that might lead to loss of life or property. Besides, with the support of a multipoint sensor network, we develop a data collection and processing system in this study, and we investigate how to extract scalogram images from the wavelet transform of the signals the sensor sends out to evaluate the state of the Offshore Jacket Platform structure. The efficiency of the proposed strategy has been demonstrated using an embedded model in MATLAB running on the STM32 NucleoF411RE central processor that collects vibration signals from the accelerometer through an Offshore Jacket Platform-installed multi-sensor network.

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1 Introduction

Marine structures come in numerous forms and are constructed for a variety of purposes. Coastal protection structures, dry-docking facilities, and berthing facilities, including Offshore Platforms (OPs), are the three main categories of marine structures based on function. Ocean oil or gas resources are widely explored, produced, stored, and transported via OPs at various depths. OPs can be classified into a broad range of categories, including self-elevating platforms, gravity platforms, Offshore Jacket Platforms (OJPs)

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[1], tension leg platforms, articulated leg platforms, guyed tower platforms, spar platforms, floating production systems, and very large floating structures [2–4]. Studying how structures react to waves, wind, and uncertain forces are necessary for the routine inspection and monitoring of OPs for certification. It is challenging to determine the precise dynamic reactions because of the platform's complicated dynamic behavior in response to external stresses [5].

To advance computer technology, deep learning, and computer vision in structural health monitoring for their outstanding benefits, many researchers have recently devoted themselves to Artificial intelligence (AI) [6] and Computer vision-based Convolutional neural networks (CNN) [7–9]. The vibration response has been the foundation for various new approaches to detecting and analyzing the structural health of offshore structures [10–13]. The method's outcomes demonstrate its capacity to identify damage based on a change in frequency. Moreover, signals can be converted from the time domain to the frequency domain and de-noised using the analytical method known as the wavelet transform. Then, converting these frequencies into scalograms simultaneously allows the system to analyze input signals and use them as data for CNN sets [14, 15]. In addition, the application of AI algorithms [16] for offshore structure shows that the proposed method can learn features from frequency data and achieve higher accuracy than other methods. In this paper, the 2D scalogram image analysis method by wavelet transform is based on the changing characteristics of the input signals mounted on the OJP's pedestal to identify the operating states of the OJP without delay. This 2D scalogram image will be an input data set for the CNN network to automatically identify OJP abnormalities in the next research work of the research group.

The remainder of the paper is organized as follows: Sect. 2 briefly explains the data collection and arrangement from the network of vibration acceleration sensors for the OJP experimental model. Section 3 shows the details of the experimental setup followed to implement the proposed damage detection method based on wavelet transform scalogram image analysis. Moreover, results are presented and discussed in this section. Finally, the conclusions of the present work are provided in Sect. 4.

2 Design a Data Collection System for the Offshore Jacket Platform Model

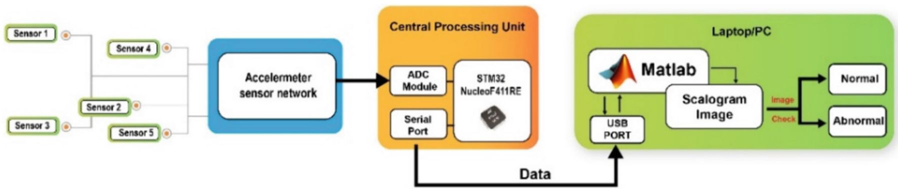


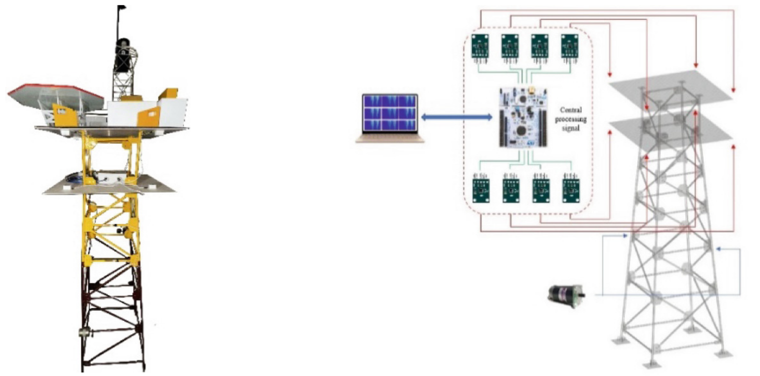
Fig. 1. A data collection system diagram for OJP.

The system is designed to operate if OJP's floor is covered with numerous sensors. These sensors are networked together and distributed and shared data through channels. In this experiment, we put on two bases of OJP 8 sensors and utilized them according to the sensor network idea that was first employed. Therefore, Fig. 1 shows the schematic diagram of the multipoint sensor network data acquisition system for OJP [17–21]. This system collected vibration signals on the surface and external influences on the model structure, such as environmental effects (waves, wind, currents, etc.), flows, earthquakes, and impacts during the operation of the OJP (rig drilling, ship mooring, crew operations, etc.) [22]. These sensors are connected to the central controller STM32 NucleoF411RE to collect input signals. By using the wavelet transform in MATLAB software to filter noise and create 2D scalogram images for analyzing OJP states, the system based on the images provides warnings. The setup and arrangement of the experimental equipment in Fig. 2 simulate the design of a steel marine structure with four main axes connected by horizontal and diagonal bars. The total height of the model is 2,0195 m, and there are 2 pedestals with dimensions of 70 × 70 cm. The device connection diagram with OJP is shown in Fig. 2b.

Table 1. The data set is collected from 8 vibration acceleration sensors.

Time (s)	Vibration acceleration (mm/s2 - G)							
	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6	Sensor 7	Sensor 8
0	−0.0863	−0.1197	−0.1344	−0.2013	−0.0475	−0.0130	0.0111	−0.0308
0.2	−0.0809	−0.1131	−0.1288	−0.2045	−0.0577	−0.0101	0.0091	−0.0338
0.4	−0.0352	−0.1266	−0.1300	−0.2079	−0.0697	−0.0008	0.0133	−0.0084
0.6	−0.0528	−0.1141	−0.1324	−0.2094	−0.0592	0.0033	0.0130	−0.0201
0.8	−0.0660	−0.1246	−0.1339	−0.2091	−0.0404	−0.0133	0.0128	−0.0218
1	−0.0218	−0.1112	−0.1459	−0.2006	−0.0499	−0.0086	0.0252	−0.1434
1.2	−0.0489	−0.1068	−0.1495	−0.2091	−0.0643	−0.0069	0.0150	−0.0643
1.4	−0.0728	−0.1061	−0.1537	−0.2037	−0.0355	−0.0135	0.0181	−0.0262
1.6	−0.0831	−0.1295	−0.1461	−0.2052	−0.0570	−0.0108	0.0064	−0.0345
1.8	−0.0362	−0.1141	−0.1422	−0.2072	−0.0626	−0.0120	0.0128	−0.0138
2	−0.0360	−0.1197	−0.1254	−0.2045	−0.0482	−0.0098	0.0130	0.0655
2.2	−0.0694	−0.1114	−0.1329	−0.2079	−0.0475	−0.0094	0.0155	−0.0245
2.4	−0.0550	−0.1251	−0.1354	−0.2076	−0.0594	−0.0008	0.0118	−0.0274
2.6	−0.0475	−0.1297	−0.1551	−0.2045	−0.0599	−0.0135	0.0098	−0.0140
2.8	−0.0699	−0.0892	−0.1664	−0.2098	−0.0728	−0.0101	0.01453	−0.0362
3	−0.0709	−0.1297	−0.1415	−0.2086	−0.0487	−0.0008	0.0130	−0.0299
3.2	−0.0592	−0.1334	−0.1444	−0.1979	−0.0484	−0.0125	0.0140	−0.0296
3.4	−0.0675	−0.1302	−0.1256	−0.1918	−0.0492	−0.0108	0.0116	−0.0084

The OJP experimental model consists of 2 pedestals as shown in Fig. 2. Each pedestal on the structure is connected with 4 accelerometers to the central controller STM32 NucleoF411RE to collect data. A vibration signal in 1000s with a sample frequency is saved on a data set as shown in Table 1 for signal input into MATLAB software using wavelet transform to filter noise and generate a 2D scalogram image signal for analysis for OJP.



(a) Experimental model (b) The device connection diagram with OJP

Fig. 2. The setup and arrangement of the experimental model.

3 Simulation and Evaluation

3.1 Wavelet Transform for the Model

The wavelet transform is a noise filtering tool for the input sensor signals before processing, which has been widely applied in recent years [23–26]. Figure 3 illustrates a signal that has been filtered by the wavelet transform. After denoising by wavelet decomposition, the high-frequency noise of the OJP is effectively eliminated.

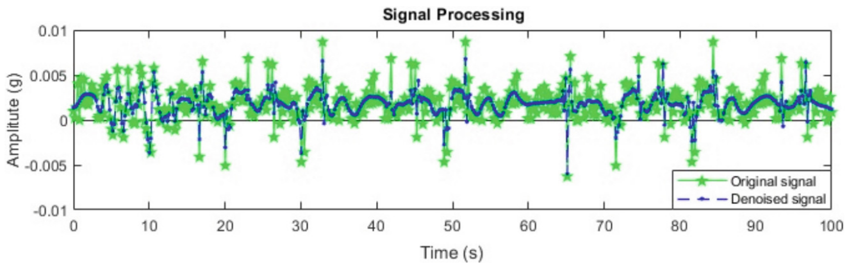


Fig. 3. Original signals and denoised signals by wavelet transform.

In addition, the application of wavelet transform [27] creates 2D scalogram images to analyze the state of the structure as well as an input image for the identification of the state of the structure using the CNN network. The wavelet transform is based on small wavelets with a limited time period. This technique starts with small waves containing fairly low-frequency oscillations, which are compared with the analyzed signal to get a rough picture of the signal at its raw resolution. The small wave is then compressed to gradually raise the frequency of the oscillation.

The continuous wavelet transform (CWT) of a signal $x(t)$ is defined as a convolution integral of $x(t)$ with scaled and dilated versions of a mother wavelet function $\Psi_{s,\tau}(t)$. Cwt is usually adopted for time-frequency analysis and is defined as [28, 29].

$$W_x(s,\tau) = \frac{1}{\sqrt{s}} \int_{-\infty}^{+\infty} x(t) * \Psi^*\left(\frac{t-\tau}{s}\right) dt \quad (1)$$

where $\Psi(t)$ is a basic wavelet, $\Psi^*(t)$ is the complex conjugate of $\Psi(t)$, s is the scale factor and τ is the translation factor. There are several different read and complex value functions that can be utilized for analyzing wavelets. In the present work, the wavelet Symlets 5 is employed as the mother wavelet owing to its similarity to an impulse component that is characteristic of OJP [30, 31].

3.2 Processing Signals System for Offshore Jacket Platform

The block diagram of the wavelet transform scalogram image analysis method for OJP using a multipoint sensor network includes the following steps:

Step 1: The signal is collected by the central controller STM32 NucleoF411RE and stored by the computer into many different datasets corresponding to the normal and abnormal operating cases of OJP;

Step 2: The received data will be normalized according to the amplitude limit of the signal. At the same time, it is divided into many smaller data sets to conduct noise filtering through the wavelet transform;

Step 3: Apply the wavelet transform to perform noise filtering for each signal set. Simultaneously transform the signal from the time domain to the frequency domain and create a 2D scalogram dataset.

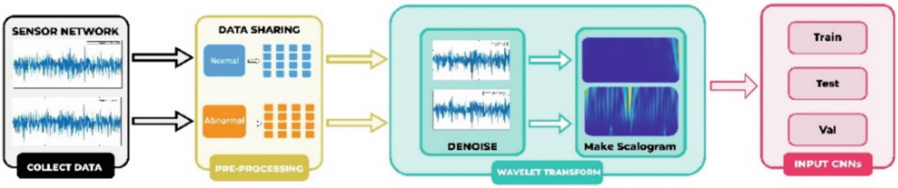


Fig. 4. The block diagram of the proposed damage detection method.

The diagram of the proposed damage detection method illustrated in Fig. 4 shows the steps of signal processing. Moreover, these 2D scalogram images (the pink color) will be used as inputs for the CNN to automatically identify abnormal states on the OJP.

3.3 Determining the Status of the Structure for the OJP

In this paper, we synthesize the forces acting on the OJP from the operation process to the effects of the environment, such as waves, wind, and currents, through 2 vibrating motors mounted on the framework of the OJP. The research group conducted the classification of impacts and simulations through the simulation system. Signals are read directly from the OJP model through the STM32 NucleoF411RE central processor and MATLAB software [32]. The whole process is saved to form the initial data set, which is suitable for analyzing 2D scalograms to detect abnormal cases of OJP. The data set has been established by the research group in the period and number of times following the specific condition from the impact for 4 cases:

Normal situation: The normal state of OJP is described as a state in which environmental impacts are at a stable level, the weather is good for operations, drilling activities and crew activities are normal stable operations, and there is no impact from the process of launching helicopters or mooring ships from outside affecting the OJP. The scalogram image of the blue normal case occupies a large area; only a few yellow streaks appear, as shown in Fig. 5.

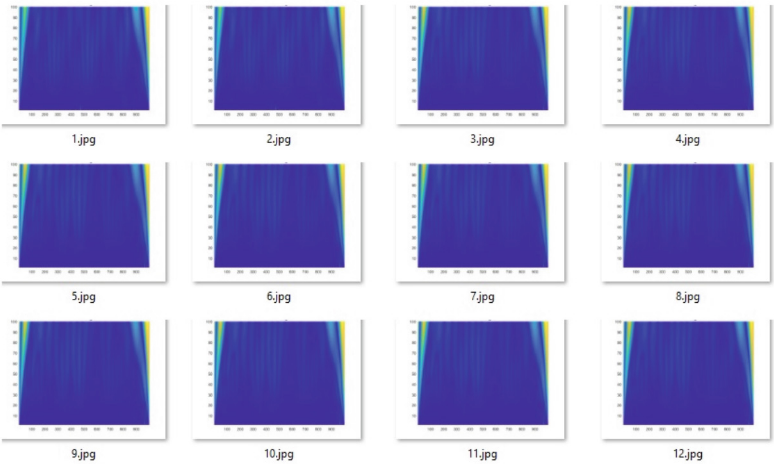


Fig. 5. Scalograms of normal condition.

Abnormal case 1: Abnormally strong waves impact the OJP leg frame at a certain frequency; the wave crest may change but is specified for the simulation as strong waves or vibrations from the seabed to the OJP. Figure 6 shows a scalogram image of 2 yellow streaks when waves or vibrations are generated.

Abnormal case 2: The machines operating on the OJP resonate with the fatigue magnetic effects of the building, causing the working surface to generate “abnormal points” with high vibration levels. The simulation will generate random vibrations at all locations on the active surface of the OJP. The simulation will generate random vibrations at all locations on the active surface of the OJP, as shown in Fig. 7.

Abnormal case 3: The impact of storms at sea on the OJP structure includes strong waves and the direct impact of high winds. During the simulation, the OJP system is subject to multiple simultaneous and multi-dimensional vibrational effects. As a result, there are many blue and yellow spikes on the scalogram, as shown in Fig. 8.

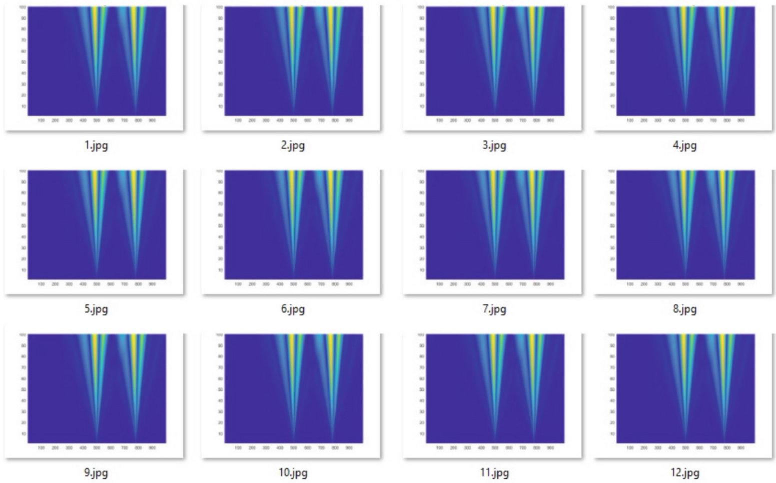


Fig. 6. Scalograms of an abnormal condition 1.

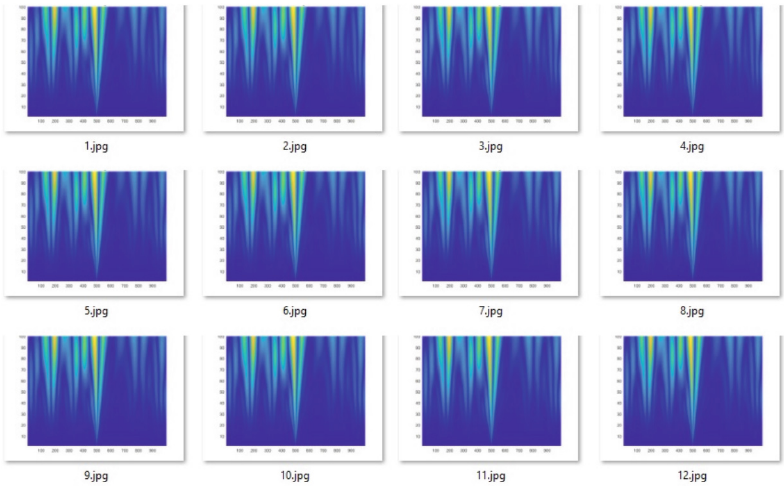


Fig. 7. Scalograms of an abnormal condition 2.

The wavelet transform application extracts different spectral histograms from the data of a multipoint sensor network placed on the OJP pedestal to determine the state of the structure on the OJP.

Figure 9 illustrates the overall impact on OJP. In the normal image field, the 2D scalogram image has a large area of the blue part. In other unusual cases, the scalogram image appears with many yellow and orange streaks alternating with green parts, showing that there are many abnormalities affecting the OJP. The diagnosis of faults and failures based on the principle of identifying the vibration signal spectrum image obtained during

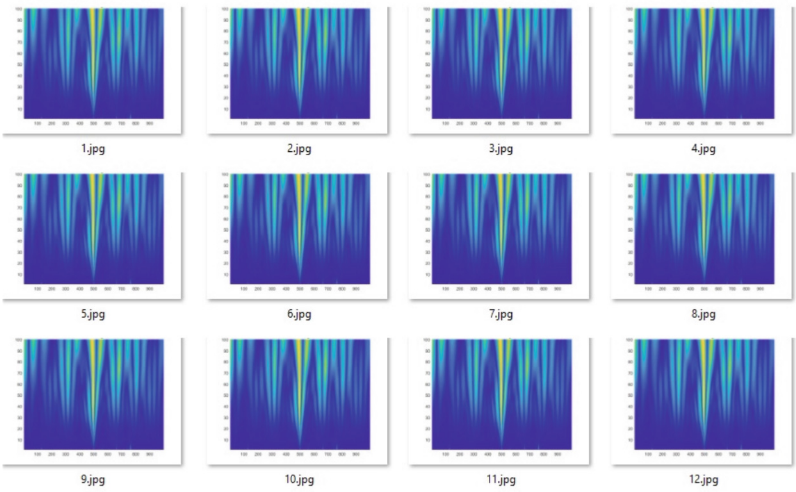


Fig. 8. Scalograms of an abnormal condition 3.

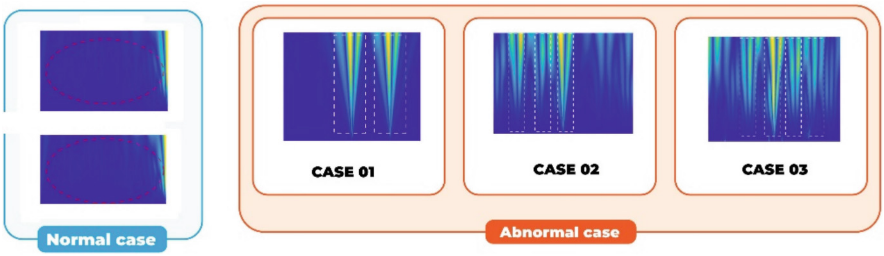


Fig. 9. Final scalograms of cases onto OJP.

operation using a deep learning neural network (CNN) must be improved in the future, along with noise filtering techniques and 2D scalogram images produced by wavelet transform. For a more thorough evaluation of this system, data will also be gathered in the various frequency domains of the industrial environment and at various data gathering distances.

4 Conclusion

In this paper, to determine the typical and abnormal conditions for offshore construction, we implement the continuous wavelet transform based on the multipoint sensor network installed on the pedestal of the OJP and exhibit the color histogram findings on the spectrum. Whenever the wavelet transform is used, the input signal from the sensor is filtered, and several scalograms with various characteristics are extracted from the input accelerometer. Wavelet transformations work well for creating scale histograms. However, the process of converting the scalogram image using a wavelet transform and feeding it into the CNN to detect any extraordinary circumstances will be done in the future.

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