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Review

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Review of Existing Solutions for Vibroacoustic Monitoring of Construction Sites

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Abstract. The article explores the potential application of various solutions that allow monitoring noise and vibration to some extent on construction sites. Over 20 scientific articles presenting experimental research and experience with noise and vibration monitoring systems were reviewed. The articles were collected from leading journals indexed by scientometric databases. The reviewed articles were categorized into solutions for noise monitoring, vibration monitoring, and multifunctional solutions. As a result of the review of solutions in the field of acoustic monitoring, important trends and prospects for further research were identified. There is a recognized need for the development of more accurate methods for filtering background noise and accounting for the characteristics of different construction sites. Regarding solutions for vibration monitoring, the review revealed a need for a more in-depth investigation into the identification and classification of vibration sources for accurate assessment of their indicators. The review of multifunctional solutions and systems showed that additional research and testing are required for a full assessment of their effectiveness and applicability in practice. Successful implementation of such systems requires attention to their flexibility and the ability to install various types and scales on construction sites. Furthermore, emphasis should be placed on training personnel for the effective use of equipment or ensuring their qualifications match the ability to use vibroacoustic complexes.

Keywords: noise, vibration, monitoring, compact urban development, sensors.

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Introduction

The modern process of building construction is characterized by numerous noise and vibration impacts. Sources of noise and vibrations include heavy machinery, equipment, tools, as well as various processes during construction works. Due to technological progress on construction sites, the use of various noisy equipment is widespread. Under the guidance of modern architects, buildings have not only acquired diverse architectural forms but have also significantly expanded, gaining more complex frameworks and internal equipment, contributing to an overall increase in noise levels [1]. Depending on the scale of construction, noise and vibration levels can reach several hundred decibels [2]. Such noise and vibration impacts can negatively affect the lives and health of residents near the construction site of residential buildings and visitors to non-residential buildings. Prolonged exposure to high levels of noise can lead to gradual hearing loss. Persistent noise can cause stress, insomnia, and other psychological problems. A high level of noise can also lead to increased blood pressure and an increased risk of cardiovascular diseases [3]. In addition, constant noise and vibration can worsen the overall quality of life, leading to negative social and psychological consequences. Vibration can also impact the operation of technical equipment and machinery in adjacent buildings, causing breakdowns and reduced efficiency of these devices. Intensive construction, especially when creating large-scale buildings, tends to increase the negative impact on the environment. This is evident in the growing number of complaints about noise and vibration worldwide. For instance, in South Korea, complaints related to noise on construction sites represent a significant portion, accounting for 64.6% of the total complaints about noise and vibration [4]. In light of this trend, the implementation of noise and vibration monitoring systems on construction sites becomes extremely important. Effectively controlling these parameters can minimize the negative impact on the environment and ensure compliance with regulations. Regular monitoring of noise and vibration can also contribute to prompt response to issues and the implementation of measures to improve conditions for local residents and the surrounding area.

The purpose of this review is to explore the potential of the solutions currently employed on construction sites for monitoring noise and vibration, as well as their advantages and disadvantages.

To initiate the review, over 40 experimental scientific articles on the measurement and monitoring of noise and vibration on construction sites were collected from reputable scientific publications. The sorting and categorization of articles were conducted in two stages. In the first stage, attention was given to the titles, abstracts, and conclusions of the articles, from which more than 20 most relevant to the review's topic were selected. Depending on the ideas conveyed in the titles, abstracts, and conclusions, the articles were sorted into three categories: 1) solutions for noise; 2) solutions for vibration; 3) multifunctional solutions.

Thus, this research aims to systematize knowledge in the field of applied tools and systems for vibroacoustic monitoring of construction sites. It is expected that the results of the study will not only deepen the theoretical understanding of noise and vibration monitoring but also have a significant impact on further advancements in this direction.

1. Solutions for noise monitoring

1.1 Review of existing solutions

The authors [5] conducted noise monitoring at 26 construction sites of various sizes throughout Kuwait using the Bruel & Kjaer sound level meter. During the study, it was found that the Equivalent Continuous Sound Pressure Level (LAeq) at a distance of 5 meters from the noise source varied from 69 to 88 dB. It is worth noting that the LAeq range includes nearly 64% of the measured noise levels at the investigated construction sites. In comparison to other noise monitoring devices, this option is used solely for measuring the noise level.

[6] invented the SAVE (Surveillance of Acoustics and Vibration in the Environment) noise monitoring system based on display boards placed at the corners of the construction site, showing the current noise level in decibels. This process involves selecting key factors, using sensor networks for monitoring, applying big data evaluation methods, and developing an intelligent system for automatic control. The scientific work by the authors [4] examines an automated system for measuring ambient noise developed by the Korean Environmental Protection Agency. This system, ensuring high reliability of noise measurement data, is actively applied on construction sites in South Korea. Features include an outdoor-use microphone with pre-calibration, a status indicator displaying the current time and the equivalent continuous sound pressure level (LAeq) over the last 5 minutes, and a data storage system recording LAeq values for various time intervals and providing storage for noise data and video recordings from the surveillance camera. The system also offers communication capabilities via telecommunication networks (LTE, CDMA, etc.) or Ethernet networks (wireless, wired LAN, etc.). A crucial aspect is continuous monitoring, octave analysis, the presence of two surveillance cameras for each microphone, built-in GPS, user customization of the permissible noise level, and an alarm for exceeding it. The study proposes a real-time monitoring method aimed at efficiently measuring parameters inside the construction site to reduce environmental pollution levels. However, simply measuring the noise impact level of some machinery and equipment operators used on construction sites does not fully reveal the extent of the health damage to which workers are exposed while performing their duties.

The authors [7] conducted noise monitoring at construction sites using the Internet of Things (IoT). For the corresponding device required for this project, a specific configuration is needed to activate the device and launch the operating system on the Raspberry Pi 3 B+ model. The device requires a minimum of 8 GB of RAM with pre-installed New Out Of Box Software (NOOBS). This helped them process measurement data faster and store the history on the hard drive. Information from the sensor passes through the Raspberry Pi. The Raspberry Pi analyzes the noise level in decibels, and then this data is transmitted for storage on a cloud server through the Favoriot platform.

Researchers [8] have developed Wireless Acoustic Sensor Networks (WASNs) for measuring noise and recognizing acoustic events in urban environments (Figure 1).

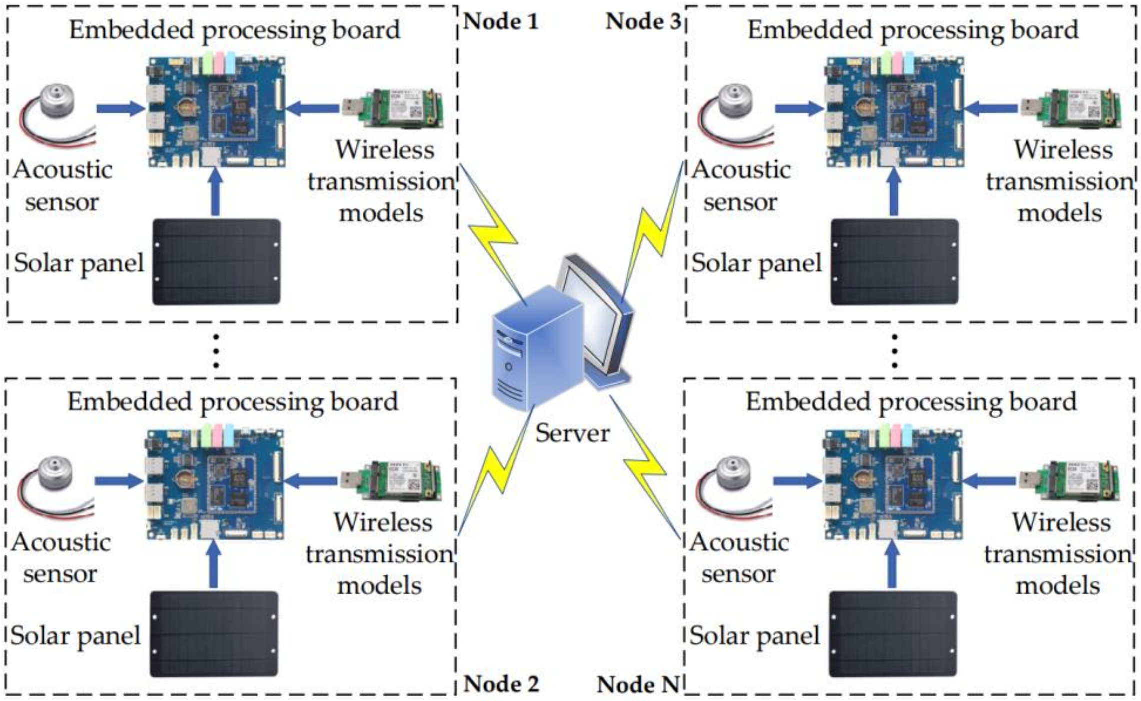

Figure 1 – Scheme of the system proposed by the researchers [8]

The feature of these networks is that signals are processed by built-in processor boards using the method of endpoint detection and the Adaptive Differential Pulse Code Modulation (ADPCM) sound encoding method, which utilizes adaptive differential quantization to compress the audio signal. Adaptive Differential Pulse Code Modulation (ADPCM) is a digital audio compression algorithm used to encode and compress audio signals while maintaining reasonable sound quality. In simple terms, this is a way of representing sound using less data. In the ADPCM process, the audio signal is analyzed, and the differences between consecutive samples are encoded, rather than the samples themselves. This reduces the amount of transmitted data while preserving important aspects of the sound. The adaptability lies in the fact that quantization (encoding of sound levels) can vary depending on the characteristics of the audio signal. Additionally, it uses a solar panel with a built-in 5V battery with a capacity of 10,500mAh, allowing the processor board to operate continuously for about two days without sunlight. It is claimed that the total cost of the sensors does not exceed $100. However, additional components such as the processor board with an extensive audio interface and a high-performance audio encoder to improve sound quality require additional expenses. Furthermore, the board is equipped with an A33 processor, which uses a 4-core CPU (CortexTM-A7: Advanced RISC Machines, Cambridge, UK) and a graphics processor (Mali-400 MP2: ARM Norway, Trondheim, Norway) with a frequency of up to 1.2 GHz. It also has 1GB of RAM and 8GB of built-in memory, making the solution relatively expensive.

The approaches discussed in the articles and studies on noise monitoring at construction sites represent a significant step towards the effective control of the impact of construction activities on the environment and people's health. The development of IoT sensor systems, including the use of microcomputers, not only demonstrates a reduction in the cost and size of systems but also the implementation of autonomous solar-powered systems, improving their mobility and sustainability. The unique approach proposed by [6], involving displays placed at the corners of the construction site to show the current noise level, emphasizes the importance of diversity and innovation in the field of monitoring. While some researchers [7] suggest using the Internet of Things for noise monitoring, others [8] present wireless networks for noise measurement and acoustic event recognition, providing adaptability and low cost. However, despite technological innovations, issues such as cost and effectiveness remain open and require further research to create more affordable and widely applicable noise monitoring systems.

1.2 Applications

High-precision Bruel & Kjaer sound level meters are capable of determining the level of impulse noise generated by machinery equipment. They are designed for measuring sound pressure levels, vibration acceleration, and analyzing sound pressure signals in 1/1 and 1/3 octave frequency bands. The utilization of these sound level meters has been documented in earlier studies, such as those conducted in the Kuwait Metro [5], the road construction in Romania [9], and various sound parameters in Denmark[10] .

Surveillance of Acoustics and Vibration in the Environment is widely employed in the United States for noise management [6]. Its frequent parameter updates (transmitting measurements to the main data processing station every five minutes) have led to its use in international locations such as the Mexico City airport [11], The convenience of wireless network operation, facilitating constant monitoring and reporting to a central dispatcher, has been recognized during its application in France [11].

Practicing construction industry professionals in Malaysia have acknowledged significant advantages attributed to the continuous monitoring of construction processes and equipment offered by the Internet of Things [12], where the system was utilized by hundreds of respondents. Meanwhile, in Hong Kong, its efficacy in noise monitoring has been underscored, even in comparison to Building Information Modeling.

While high-precision sound level meters offer accurate measurements, their widespread use raises concerns about cost and accessibility. The surveillance system provides real-time updates but may face challenges related to infrastructure costs. While the Internet of Things offers advantages in continuous monitoring, its efficacy in noise monitoring requires further evaluation.

2. Solutions for vibration monitoring

2.1 Review of existing solutions

The authors of the study [13] presented an autonomous system for monitoring bridge vibrations. In addition to an economical sensor system for monitoring structural characteristics, the authors also developed software for analyzing vibration characteristics using RESNIK AND GERSTENBERG. The work utilizes a 3-axis accelerometer based on a micro-electromechanical system (MEMS) (WILD-PFEIFFER AND SCHÄFER) and is equipped with a memory card slot and a built-in battery. A micro-electromechanical system (MEMS) is a technology that integrates mechanical and electrical components at a very small scale, typically at the microscale level, ranging from micrometers to millimeters. The battery allows the device to operate for about 8 hours at maximum power consumption and up to 80 hours under normal conditions, making it an effective tool for measurement processes. The measurement procedure and subsequent data analysis are illustrated using the example of the Komtur Bridge in Berlin, Germany. This bridge was chosen due to its pronounced and clearly perceptible vibrational behavior.

Article [14] describes the development of an affordable and flexible data collection system for long-term continuous monitoring of structural conditions through vibration. The main challenges involve a limited budget, the remote location of sensors, and complex ambient vibration conditions. Multilevel solutions are proposed, including the selection of suitable accelerometers and their optimal placement, as well as the use of an Ethernet-based DAQ model to reduce costs. A data synchronization method is suggested using TCP/IP for time coordination and periodic system resynchronization.

In article [15] , the development of an Internet of Things (IoT) sensor system for monitoring vibration induced by construction and assessing its impact is discussed. The use of a Raspberry Pi microcomputer and MEMS accelerometer is described to reduce the cost and size of the system. The system includes remote data transmission and access features, as well as autonomous power from a solar battery. Successful tests were conducted in the laboratory and on a construction site, confirming the effectiveness of the system.

In the scientific study [16] , vibration monitoring was carried out on the Qingdao metro in China, from Lijia Xiazhuang station to Laoshan station. The vibration monitoring system includes instruments such as the vibrosensor 941 B, shown in Figure 2, and the Universal Dynamic Data Collector D1000A. Apparently, such vibration sensors are primarily used for measuring ultralow or low-frequency vibrations, and the cost of just one unit on the market exceeds $1000.

Figure 2 – Vibration sensor 941 B (manufactured in China) [8]

The authors of article [17] conducted a study on monitoring vibrations resulting from explosions during the construction of a new tunnel adjacent to an existing railway tunnel. They employed a wireless sensor network (WSN) to monitor concrete stress and peak particle velocity (PPV) in the surrounding environment. The authors deployed a WSN consisting of the UBOX-5016 explosive vibration monitoring system and the SZYC wireless remote data collection system in the existing tunnel in the Shaanxi province, China. They placed velocity and deformation sensors on the tunnel walls, transmitting data through a wireless local area network (WLAN) to a computer for analysis. They also performed preliminary data processing, including DC removal, noise reduction, and digital filtering. The authors concluded that WSN is an effective tool for monitoring vibrations during explosions in an existing tunnel, simplifying the data collection and transmission process and expediting feedback based on monitoring results.

The discussed studies on structural vibration monitoring underscore the importance of developing innovative and cost-effective systems to ensure the safety and durability of infrastructure. Moreover, existing solutions are tailored for complex construction projects such as bridges and metro systems. Autonomous systems, as presented in works [13] and [14], demonstrate the effective use of modern technologies, including 3-axis accelerometers and Ethernet-based data collection models. However, despite technical advancements, the high cost of existing sensors emphasizes the need for more affordable technological solutions. Further steps in this field may involve the development of budget-friendly sensor options and the enhancement of data collection and analysis methods, which could be a crucial factor in the application of monitoring systems for vibration measurement on construction sites.

2.2 Applications

The use of MEMs technology is mentioned in the measurement of vibrations near the Comtur Bridge in Berlin, Germany. At sites in Diamond Valley Lake in California, USA, an automated and integrated monitoring system was utilized. This vibration monitoring system has also been implemented in Armenia [13].

Due to the convenience of data processing, the Data Acquisition System (DAQ) is widely used in monitoring the condition of structures at the Gardens Point Queensland University of Technology (QUT) campuses in Brisbane, Australia. This system, with its high precision data processing, is used not only in construction but also in medicine, for example, in measuring vibrations of various body rhythms [18].

The use of Wireless Sensor Networks (WSN) in construction is not only widely developing but also being modified for specific construction applications. In the work [17], five prototype projects supporting current outdoor and indoor construction practices are presented. The application of WSN is also actively evolving in conjunction with work in Building Information Modeling Technologies [19].

The application of MEMs technology, automated monitoring systems, data acquisition systems, and wireless sensor networks in construction not only enhances monitoring efficiency and accuracy but also fosters innovation and improves processes in the construction industry and beyond, such as in medicine. However, it is essential to study the potential cost implications of implementing these technologies to ensure their affordability and sustainability in the long run. These technologies open up new possibilities for creating sustainable and safe environments for living and working.

3. Multifunctional solutions for monitoring both noise and vibration

3.1 Review of existing solutions

Researchers [20] conducted noise and vibration monitoring using "The Press-in Piling Method". Measurements were taken at five different sites in Singapore. The Super Crush Piler, employing its vibratory hammer, was used to drive the piles to the planned depth. Vibration monitoring was also conducted during the quieter pile driving process. Devices for noise and vibration measurement, Svantek 917 from the Singaporean company Absolute Instrument Systems (Pte.) Ltd., were selected for monitoring. This class of sound level meter is designed for measuring noise in workplaces and building acoustics. The sound level meter utilizes a microphone that enables linear measurements in the range of 27 to 140 dB. For ease of use, this sound level meter employs specialized mobile applications that support sound level measurements, as well as measurements of Reverberation time (RT60) and Speech Transmission Index for Public Address (STIPA). To evaluate the measured data, researchers created a peak particle velocity (PPV) level graph in relation to the logarithm of the distance from the source (Figure 3).

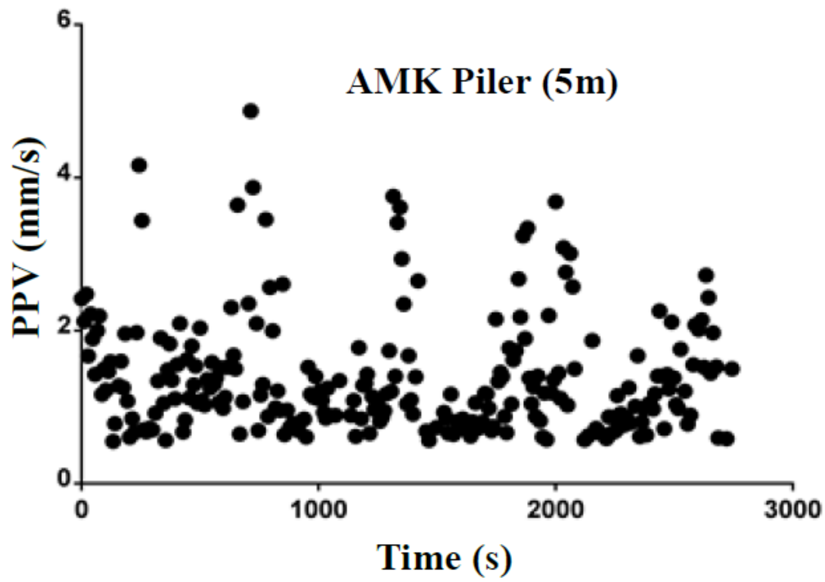

Figure 3 – Peak Particle Velocity (PPV) Level Graph in Relation to the Logarithm of the Distance from the Source

The authors emphasized the need for filtering recorded raw vibration data to obtain accurate measurements. Proper interpretation of the data requires relevant training and experience, as it was evident that the vibro hammer created much higher vibration levels compared to the silent driving at all five sites. Another equipment for noise and vibration measurement is the

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MONVID system developed by [21]. In addition to noise and vibration, the system measures dust levels. When developing the MONVID hardware (Figure 4), the following considerations were taken into account. First and foremost, the positioning of measurement sensors was considered (noise and dust sensors: above 1.2 m from the ground; vibration sensor: at ground level). The Central Processing Unit (main device) was designed to be installed on an adjustable-height construction tripod. According to the noise and vibration measurement standards for regulation and control set by the Ministry of Environment of South Korea [22], noise and dust sensors can be installed at a distance of 1.5 m from the soundproof walls of the construction site and 1.2 m from ground level.

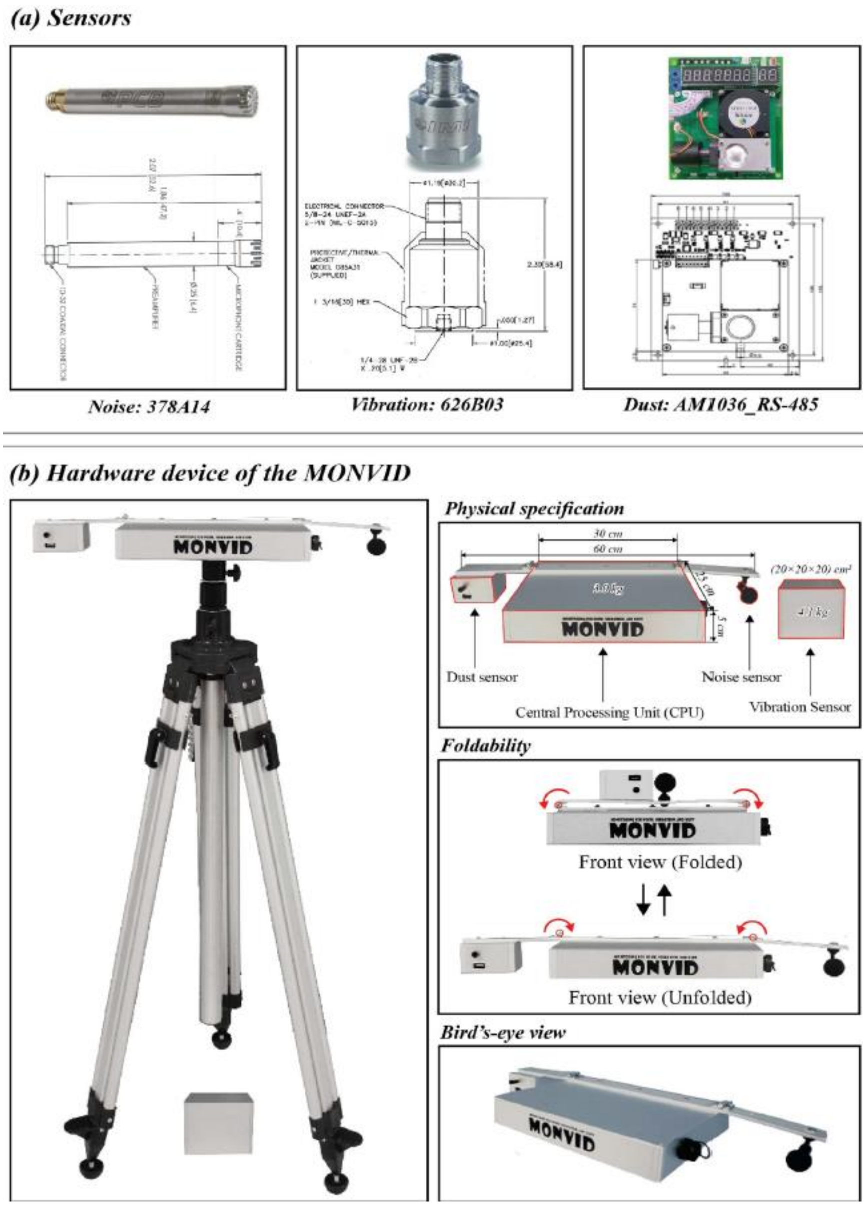

Figure 4 – MONVID Hardware Device Scheme

The cable connecting the vibration sensor to the main device was used to position it at ground level. Additionally, the noise and dust sensors were spaced 60 cm apart to prevent interference from the motor sound generated by the dust sensor in the operation of the noise sensor. The vibration sensor was designed as a cube weighing approximately 4.1 kg with a side length of 20 cm to ensure stability and accuracy. Moreover, the MONVID hardware device design was developed for ease of carrying and storage. In another scientific study [23] the use of the Unity 3D Engine system is proposed for visualizing noise assessment results, aiding site managers in noise management. A distinctive feature of this system, in addition to using noise measurement sensors, is the use of unmanned aerial vehicles (UAVs). In [24] research on the development of a wireless sensor network (WSN) for noise monitoring at construction sites using Bluetooth Low Energy (BLE) is presented. One of the key advantages of BLE is low energy consumption, opening possibilities for integrating energy harvesting technologies. The feasibility of using WSN for the identification and triangulation of noise sources, such as vehicles, is demonstrated.

The authors [25] propose a concept of a system consisting of multiple noise sensors connected to a data collector. The data collector transmits real-time data to a server, where it is analyzed and visualized as heat maps on an interactive map. Researchers employ an inverse problem in which points with known values of sound pressure are considered equivalent to sound source points. Formulas are then applied to determine the sound pressure level at any other point, given its distance from the sound source. The noise sensor concept comprises three main parts: a housing with electronic components, a microphone sensor attached to the top, and a vertical rod with a sharp end, to which all components are attached. The sensor should be lightweight, durable, and easily movable around a construction site.

Thus, the research presented in works on multifunctional noise and vibration monitoring contributes significantly to the field of monitoring the impact of construction activities on the environment. The use of innovative devices, such as the Svantek 917 sound level meter and the MONVID system, provides accurate measurements, considering various factors such as sensor height and an adjustable tripod. The need for data filtering for precise result interpretation is emphasized, along with the importance of training and experience in vibration data processing. An interesting aspect is the diversity of approaches, such as the use of drones in [14] and wireless sensor networks based on Bluetooth Low Energy (BLE) in [15], reflecting the ongoing technological advancements in monitoring on construction sites. However, there is a noticeable need for additional research on the cost and effectiveness of such systems to facilitate their broader implementation in engineering practice. After all, the main goal of such monitoring is to reduce the impact on the environment and the health of people on construction sites [26].

3.2 Applications

The Svantek 917 system is widely utilized for multifunctional measurements, particularly during explosive operations in Poland, where both noise and vibration levels need to be assessed [27]. Additionally, in Singapore and Japan, this system finds extensive application in the construction industry [20].

Researchers [28] emphasize the cost-effectiveness of the MONVID system compared to other analogous solutions, driving its active utilization not only in Korea but also in various countries worldwide. Moreover, updated versions of this product, such as MONVID II, have been released, further enhancing its efficiency.

The widespread application of multifunctional monitoring systems underscores their significance in diverse global contexts. However, challenges related to cost, compatibility, and training requirements highlight the need for continuous advancements and adaptations to meet evolving industry needs. Nonetheless, addressing issues related to infrastructure and data management is essential to enhance their effectiveness and widespread adoption in various regions.

Conclusions

The article presents a comprehensive review of existing solutions for vibroacoustic monitoring of construction sites. It demonstrates a wide range of devices and methods for measuring noise and vibration, each with its strengths and weaknesses. The review also highlights that some solutions can combine noise and vibration monitoring in a single system, potentially enhancing efficiency and measurement accuracy. However, it acknowledges ongoing challenges and limitations in the implementation and application of these solutions, such as high costs, complex data analysis, interference from other sources, and a lack of standardization.

Various approaches to noise and vibration monitoring on construction sites were examined during the review, with an emphasis on identifying their advantages and disadvantages. Three main categories of solutions were identified: noise monitoring, vibration monitoring, and multifunctional monitoring of both parameters.

Noise monitoring solutions involve the use of advanced technologies such as IoT sensor systems, solar panels, wireless networks, and data visualization. Despite these advancements, challenges persist in terms of accuracy, cost, and the effectiveness of such systems, as well as in filtering background noise and considering the unique features of different construction sites.

Vibration monitoring solutions aim to ensure the safety and durability of infrastructure objects such as bridges and subways. Various types of accelerometers, Ethernet-based data collection models, and methods for data synchronization and analysis are applied. However, the high cost of sensors and the complexity of identifying and classifying vibration sources require further research.

Multifunctional solutions for noise and vibration monitoring integrate various approaches and devices, including sound level meters, the MONVID system, drones, and Bluetooth Low Energy (BLE). These solutions offer the opportunity to assess the impact of construction activities on the environment and people's health from various perspectives. However, additional research and testing are needed for a complete assessment of their effectiveness and applicability in practice.

The research results emphasize that vibroacoustic monitoring of construction sites can help identify regulatory violations of noise and vibration. Monitoring key indices can reduce the exceedance of noise and vibration levels by up to 61.7% [29].

To sum up, the review has identified a diversity of solutions for noise and vibration monitoring. However, challenges and issues requiring further research and development persist. Prospects for future research include developing more affordable, accurate, and flexible systems, improving methods for data processing and visualization, and considering the specificity of different types and scales of construction sites.

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Құрылыс алаңдарын виброакустикалық бақылау бойынша қолданыстағы шешімдерді қарастыру

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Аңдатпа. Мақалада құрылыс алаңдарында пайда болатын шу мен дірілді бақылауға мүмкіндік беретін әртүрлі шешімдерді қолдану мүмкіндігі ашылады. Шу мен дірілді бақылау жүйелерімен тәжірибелік зерттеулер мен тәжірибені білдіретін 20-дан астам ғылыми мақалалар қарастырылды. Мақалалар ғылыми-метрикалық деректер базасы арқылы индекстелген жетекші журналдардан жиналды. Қаралған мақалалар бірнеше санатқа бөлінді: шуды, дірілді бақылау шешімдері және біріктірілген шешімдер. Акустикалық мониторинг саласындағы шешімдерді шолу маңызды тенденцияларды және одан әрі зерттеулердің перспективаларын анықтады. Фондық шуды сүзудің және әртүрлі құрылыс алаңдарының сипаттамаларын ескере отырып, дәлірек әдістерді әзірлеу қажеттілігі анықталды. Діріл мониторингінің шешімдерін шолу олардың өнімділігін дәл бағалау үшін діріл көздерін анықтау және жіктеу мәселесін тереңірек зерттеу қажеттілігін көрсетті. Күрделі шешімдер мен жүйелерді шолу олардың тиімділігі мен практикада қолданылуын толық бағалау үшін қосымша зерттеулер мен сынақтар қажет екенін көрсетті. Мұндай жүйелерді сәтті енгізу үшін олардың икемділігіне және әртүрлі типтегі және өлшемдегі құрылыс алаңдарында орнату мүмкіндігіне назар аудару керек. Сонымен қатар, персоналды жабдықты тиімді пайдалануға немесе олардың виброакустикалық кешендерді пайдалану қабілетіне сәйкестігіне оқытуға назар аударған жөн.

Түйін сөздер: шу, діріл, бақылау, тар қала аудандары, сенсорлар.

Обзор существующих решений по виброакустическому мониторингу строительных площадок

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Аннотация. В статье раскрыт потенциал применения различных решений, позволяющих в той или иной мере производить мониторинг шума и вибрации, возникающих на строительных площадках. Рассмотрены более 20 научных статей, представляющих экспериментальные исследования и опыт работы с системами мониторинга шума и вибрации. Статьи были собраны из ведущих журналов, индексируемых наукометрическими базами. Рассматриваемые статьи были разделены на несколько категорий: по решениям для мониторинга шума, вибрации, комплексные решения. По результату обзора решений в области акустического мониторинга выявлены важные тенденции и перспективы для дальнейших исследований. Обнаружена необходимость разработки более точных методов фильтрации фонового шума и учета особенностей различных строительных площадок. По результату обзора решений по вибрационному мониторингу выявлено, что существует потребность в более глубоком исследовании проблемы идентификации и классификации источников вибрации для точной оценки их показателей. Обзор комплексных решений и систем показал, что для полной оценки их эффективности и применимости в практике требуются дополнительные исследования и тестирование. Для успешного внедрения таких систем необходимо уделять внимание их гибкости и возможности устанавливать на строительных площадках различных видов и масштабов. Более того, стоит обратить внимание на обучение персонала для эффективного использования оборудований либо соответствие их квалификации на способность использования виброакустических комплексов.

Ключевые слова: шум, вибрация, мониторинг, стесненная городская застройка, сенсоры.

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