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Wireless accelerometers: can they be useful for understanding drone vibration in flight?

Session: Experimental Aeroacoustic Measurements

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Abstract. This paper introduces a recently developed wireless vibration measurement system by Hottinger Brüel & Kjær that is expected to be useful for the experimental structural analysis of flying drones. Analyzing noise emission from drones often requires a good understanding of how the structure vibrates. However, obtaining vibration data from a flying drone using conventional measurement techniques can be challenging due to the weight of the data acquisition system. Wireless accelerometers address this limitation. The lightweight miniature wireless accelerometers (22 g each) can collect high-frequency vibration data (up to 1.6 kHz) across three measurement axes. The acquired data is synchronized between sensors, enabling phase analysis across different measurement locations. The measured vibration data from a flying drone enables further analysis, ultimately contributing to the reduction of drone noise. Due to limited access to sufficiently large drones, this paper demonstrates the use of the sensors on a lightweight sport bike, where accelerometers are also mounted on rotating elements, such as wheels and pedals.

Keywords: wireless; vibration; sensor; accelerometer

1. Introduction

Sound and vibration are closely related physical phenomena. Sound, a back-and-forth motion of particles in a medium, is often generated by the vibration of a structure. When a drone flies, it disturbs the surrounding air, causing pressure waves that propagate through the medium. Sound waves reach our ears, they are perceived as sound, or noise.

Measuring vibration is therefore essential for determining an acoustic footprint. Analyzing these vibrations provides insight into how noise is generated and transmitted. By capturing vibration data from a drone, researchers and engineers can identify the sources, frequencies, and amplitudes that contribute to sound emissions. This enables a more precise understanding of how noise propagates through different materials and environments, often before it becomes audible.

Using traditional wired accelerometers to measure the vibration of a flying drone is particularly challenging due to both physical and operational constraints. The presence of cables adds extra weight and can interfere with the drone’s aerodynamics, potentially affecting stability and flight performance. In addition, cables can introduce unwanted forces or constraints that alter the drone’s natural vibration behaviour, leading to inaccurate measurements. Managing wiring during flight is also difficult, as cables can tangle with moving parts such as propellers or become damaged under dynamic conditions.

Wired systems also limit mobility and measurement range, making it impractical to capture vibration data during free flight or in real-world operating environments. The need for a physical connection to data acquisition equipment restricts testing to controlled setups that may not reflect actual flight conditions. These limitations highlight the need for alternative solutions, such as wireless sensors or onboard data logging systems, which are better suited to accurately assessing drone vibrations and their corresponding acoustic characteristics.

The HBK Molecu wireless accelerometer shares many characteristics with a conventional wired accelerometer including a miniature design, the ability to deliver raw data, a frequency bandwidth of up to 1.6 kHz, and synchronization between sensors. Its main limitations are the restricted operational time, due to battery capacity, and the lack of feedback: during measurement, data is stored locally on the device. Once measurements are complete, the stored data must be downloaded to a computer for quality checks and post-processing.

Wireless accelerometers enable measurements in locations that are not accessible with wired accelerometers, particularly on rotating parts of a structure. This capability is especially relevant for drones, where sensors can be mounted directly on propellers.

The paper is organized as follows: Section 1 describes the methodology, including the test object and measurement setup; Section 2 presents the analyzed results and discussion; and Section 3 provides the conclusion.

2. Methodology

As access to a suitable test drone was not available, a sport bicycle was used to illustrate how the measurement approach can be applied and the types of analysis that can be performed.

2.1 Test object: Bicycle

The test object is an Omnium CXC Ti V3IR bicycle, featuring a titanium frame, and carbon components including the fork, rims, seat post, and handlebar. A series of tests were conducted to demonstrate the practical application and advantages of wireless accelerometers.

The test sequence was designed to capture a range of operating conditions. The cyclist began pedalling, passed over the kerb, made a turn, passed over the kerb a second time, and finally braked to a stop. The full test lasted 35 seconds. Two test conditions were used to assess the influence of tyre pressure on vibration behaviour. The first test was conducted with fully inflated tyres at 2.8 bar, and the second with a reduced pressure of 1.5 bar. Figure 1 shows the bicycle in motion as it passes over the kerb.

As illustrated in Figures 2 and 3, the sensors were strategically positioned at multiple locations on the bicycle. The wireless configuration made it easy to mount accelerometers on rotating components, specifically the wheel and the pedal, where the use of traditional wired accelerometers would be impractical.

During testing, vibration data was collected at a sampling frequency of 4086 Hz. Each accelerometer measured vibrations along three axes, resulting in a dataset of 21 synchronized vibration signals.

Figure 1: First bump (kerb).

Figure 2: Test bicycle measurement points: 1. Handlebar; 2. Seat post; 3. Frame downtube; 4. Rear drop downtube 5. Pedal; 6 and 7: Wheel; 8. Fork and 9. Frame.

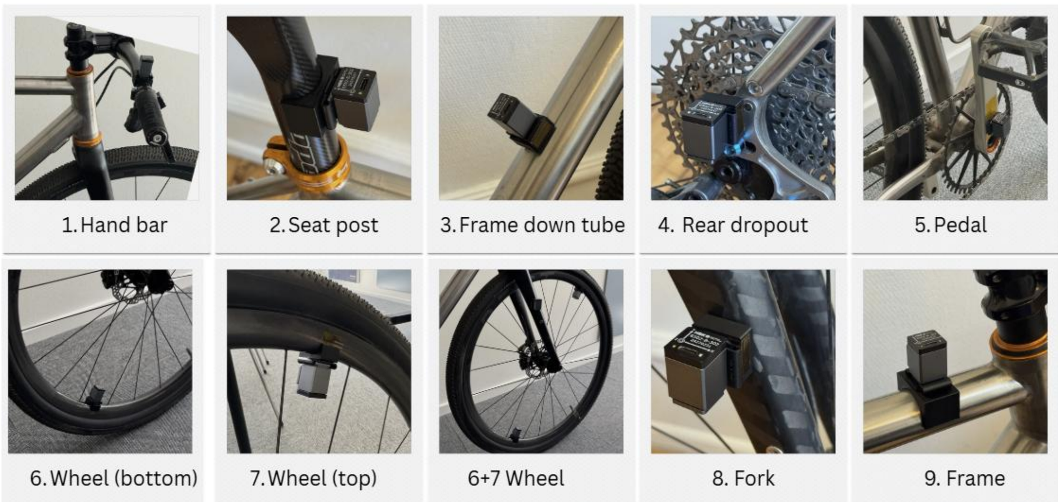

Figure 3: Accelerometer measurement points.

2.2 Data Acquisition

The wireless accelerometers used are HBK Molecu wireless accelerometers. They are tri-axial, MEMS-based sensors with an embedded rechargeable battery. The sensors are compact, measuring 18.6 × 18.6 × 19.4 mm and weighing 22 grams.

Each sensor records time-domain vibration data and stores it in the built-in memory (up to 2

Gbit). Fast Fourier Transform (FFT) processing can be performed directly on the sensor, and this capability is utilised in the described test case.

The accelerometer signals are sample-synchronous, with a time error of ±33 μs over a 10-minute measurement period, corresponding to approximately 1° phase error at 100 Hz.

The accelerometers operate in several states, including sleep, awake, armed, recording, and transmitting. These states are displayed in the accompanying graphical user interface (GUI). For ease of use, two coloured LEDs indicate the current operational mode.

Figure 4: Overview of the measurement setup.

The accelerometers are controlled via a gateway that operates on two radio frequencies: 868 MHz for configuring data acquisition parameters and 2.4 GHz for data transfer. The gateway is connected to a Windows® PC via Ethernet and USB cables, which are used to transfer commands and data, respectively. Figure 4 shows the measurement setup.

The distance over which the gateway can reliably communicate with the accelerometers depends on the surrounding environment. For configuring and starting measurements, the 868 MHz radio channel is used, allowing distances of over 30 metres, depending on the conditions. For transferring data from the sensors to the computer, the 2.4 GHz radio channel is used. To ensure fast data transfer, it is recommended that the sensors are positioned closer to the gateway. In the present case, both configuration and data transfer were performed with the gateway located approximately 4 metres from the test object. During measurement, the sensors and the gateway do not communicate, meaning the distance between them is not constrained. In this case, the distance exceeded 30 metres while the bicycle was in motion.

The accelerometers are controlled using simple open-source software that enables configuration of data-acquisition parameters, starting the acquisition, downloading and displaying the raw time data, and storing it in the universal binary file format Type 58b [10]. An Application Programming Interface (API) is also available, allowing data acquisition to be integrated into a dedicated workflow using Python, C#, or other programming languages.

3. Results and Discussions

This section demonstrates different types of analysis that are also considered useful for drone measurements.

3.1 Time, Frequency, and Overall analysis

To begin the analysis, a time-domain graph is presented in Figure 5 showing the recorded acceleration signals under two conditions – high pressure and low pressure. This initial plot provides an overview of the vibrations measured while the bicycle was in motion. Key events are clearly visible, including the moments when the bicycle passed over kerbs and the final braking action at the end of the test. Even at this initial stage, the damping effect of the lower tyre pressure is already apparent.

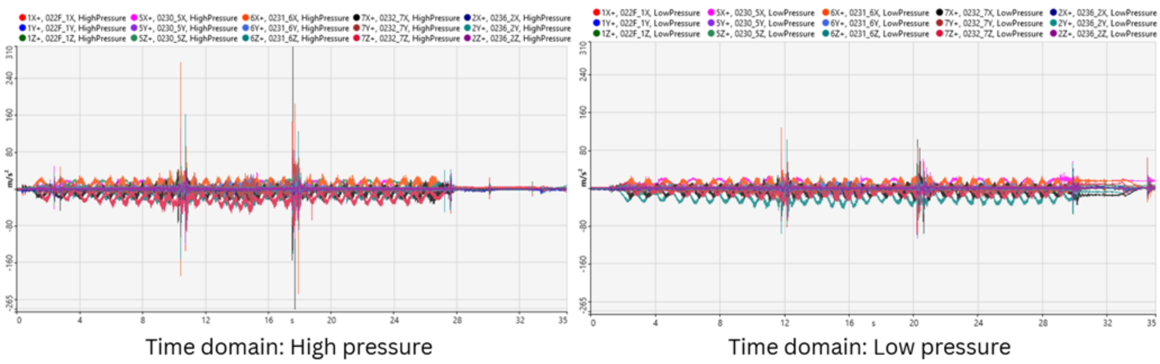

Figure 5: Time domain measurements – **h**igh and low pressure.

The sensors placed on the pedal and the wheel provide estimates of the pedal and wheel rotation speed. Due to the effect of gravity, the low-frequency component of the vibration corresponds to the pedal or wheel rotation speed (Figure 6). This reduces the need for a dedicated tacho probe for rotation-speed measurements. With these sensors, it is possible to measure direct impact, transmission vibration, and to analyse rotational dynamics and potential wheel imbalances. Figure 6 shows the time-domain results for the sensor on the bicycle wheel.

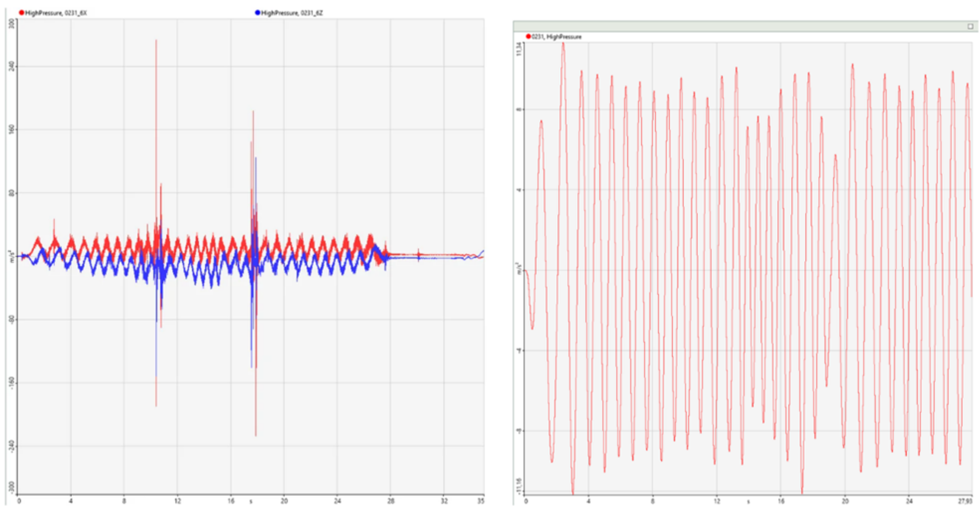

Figure 6: Left: Raw time-domain signal from the sensor on the wheel; Right: The same signal after post-processing (low-pass filter).

For demonstration purposes, three sensor positions are presented in this analysis: handlebar, seat post, and wheel.

Handlebar. The measurement at the handlebar is a critical vibration point for the cyclist's comfort. High vibration levels can cause hand-arm fatigue, numbness, and long-term joint or nerve damage (such as Hand-Arm Vibration Syndrome). Excess vibration also reduces the rider's grip, control, and steering stability, increasing the risk of accidents. Measuring handlebar vibration helps engineers design improved suspension systems, tyres, and frame materials to better dampen these forces.

Figure 7 presents the raw time-domain vibration signals along the X, Y, and Z axes on the handlebar for both conditions: high pressure and low pressure. Because extracting clear insights directly from time-domain waveforms can be challenging due to their complex and overlapping nature, an overall analysis was performed, as shown in Figure 8. The overall analysis calculates a single value representing the total vibration energy of the vibration signal over the measured period, allowing direct and easy comparison across the different axes. Since the overall vibration levels at the handlebar were highest along the Y-axis, this axis was selected for a more detailed frequency analysis, shown in Figure 9.

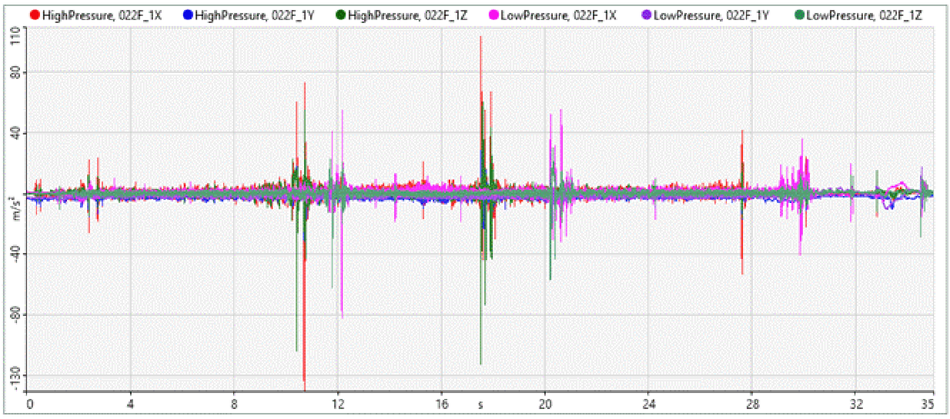

Figure 7: Handlebar accelerometer X, Y and Z time domain.

Data Name - (6/6)	Condicao	Overall (Linear) [m/s²]
022F_1X	HighPressure	0,415
022F_1Y	HighPressure	3,32
022F_1Z	HighPressure	0,122
022F_1X	LowPressure	0,792
022F_1Y	LowPressure	3,11
022F_1Z	LowPressure	0,144

Figure 8: Handlebar accelerometer X, Y and Z overall analysis.

Figure 9 focuses on the detailed frequency analysis of the Y-axis. It begins with an FFT comparison between the high-pressure and 'low-pressure conditions, showing the average frequency differences. The figure then presents an FFT vs. Time plot (spectrogram) for each condition. This type of analysis is especially useful for understanding structural vibration, as it shows exactly when specific frequencies occur and helps identify transient events by matching vibration spikes to specific moments in time.

Seat post. Following the same methodology, Figure 10 presents the time-domain vibration data for the bicycle seat post. An overall analysis (Figure 11) was again used to identify the most critical direction, which in this case was the X-axis, and the subsequent analysis therefore focuses on this axis.

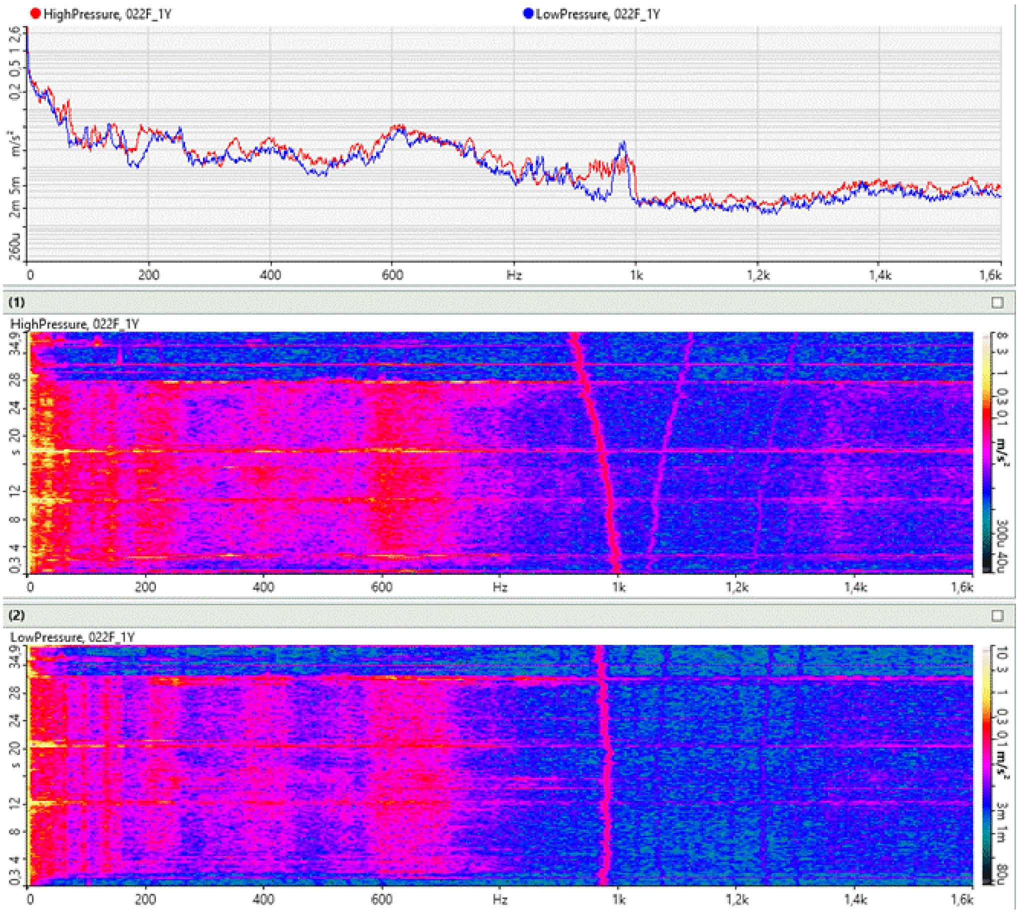

Figure 9: Handlebar accelerometer Y direction FFT and FFT vs. Time.

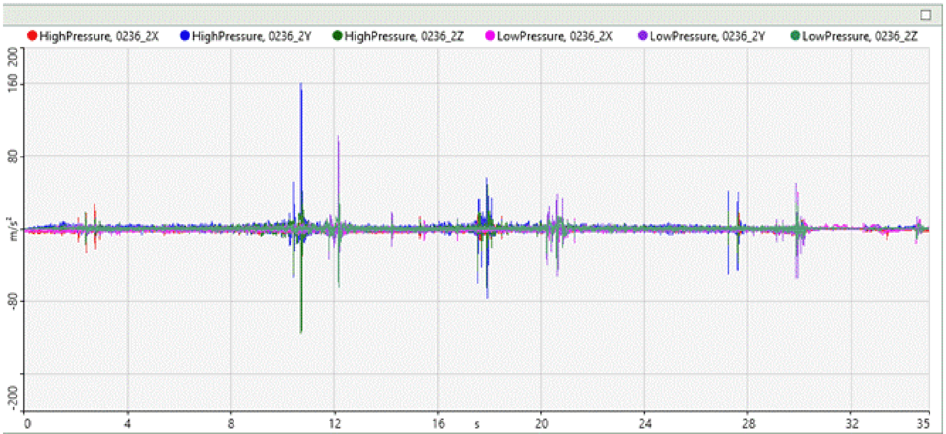

Figure 10: Seat post accelerometer X, Y and Z time domain.

Data Name - (6/6)	Condicao	Overall (Linear) [m/s²]
0236_2X	HighPressure	3,27
0236_2Y	HighPressure	0,152
0236_2Z	HighPressure	0,163
0236_2X	LowPressure	3,14
0236_2Y	LowPressure	0,844
0236_2Z	LowPressure	0,151

Figure 11: Seat post accelerometer X, Y and Z – overall analysis.

Figure 12 presents a frequency-domain analysis of the seat post's X-axis, again using both FFT and FFT vs. Time techniques. Focusing on this axis is particularly important because the seat post and saddle transmit road-induced vibrations directly to the rider's body, which supports the majority of their weight.

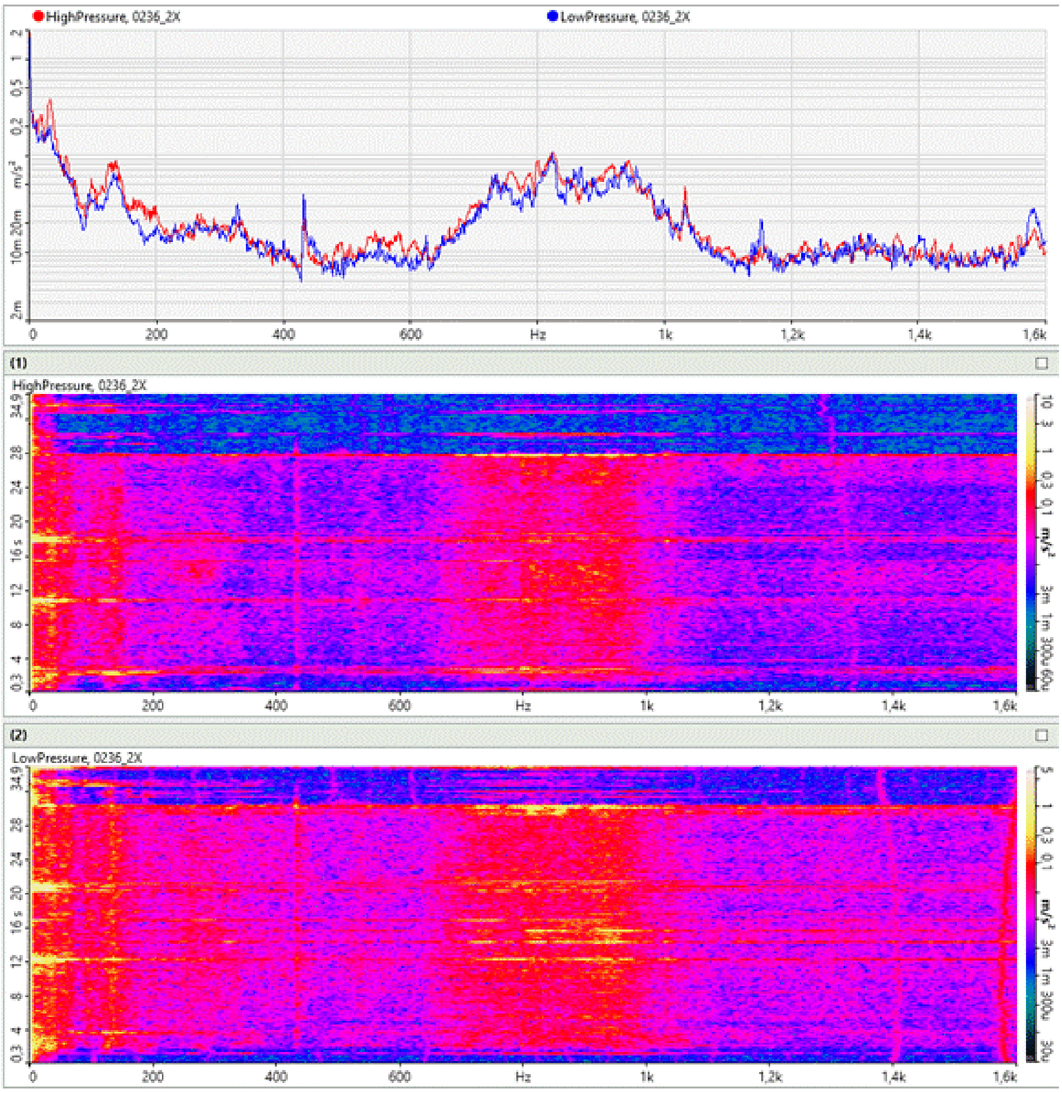

Figure 12: Seat post accelerometer X direction, FFT and FFT vs Time.

Wheel. Finally, the vibration results for one of the accelerometers installed directly on the bicycle's wheel are presented. Figure 13 displays the raw signals captured in the time domain. Measuring vibration at this location offers both significant advantages and unique challenges. The primary challenge lies in the constant rotation of the wheel: as it spins, the accelerometer's X, Y, and Z axes continuously change orientation relative to the bicycle frame and the ground. As a result, a purely vertical impact from the road is recorded as a complex combination of signals across all three axes, with the specific signature of an impact depending entirely on the wheel's rotational position at that exact moment. The main advantage, however, is the ability to capture vibration data directly at its source – the interface between the road and the bicycle. This provides the most direct and unfiltered measurement of the inputs entering the system before they are damped or altered by the tyre, spokes, or frame.

As in the previous cases, the axis with the highest overall vibration level was selected for the frequency-domain analysis. Figure 14 presents the overall results, and further analysis for axis Y is shown in Figure 15.

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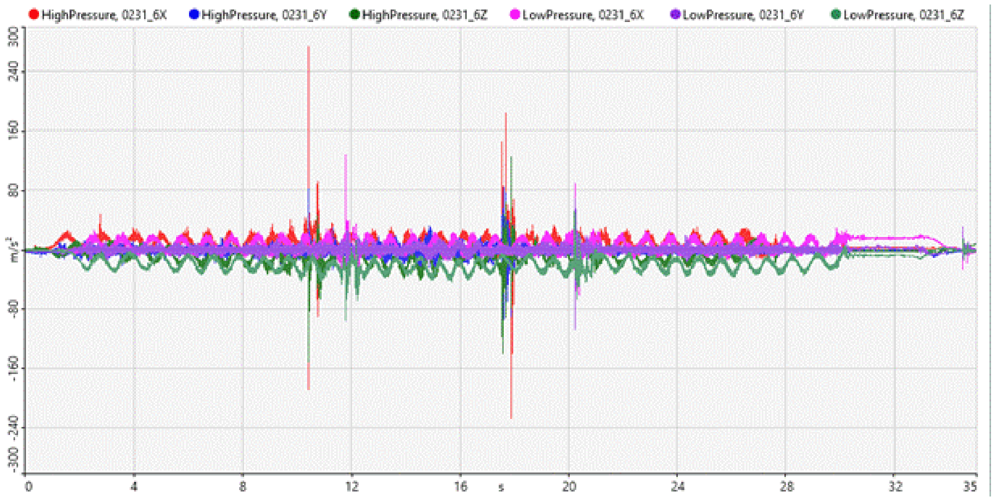

Figure 13: Wheel accelerometer X, Y and Z time domain.

Data Name - (6/6)	Condicao	Overall (Linear) [m/s^2]
0231_6X	HighPressure	0,426
0231_6Y	HighPressure	3,43
0231_6Z	HighPressure	0,113
0231_6X	LowPressure	2,14
0231_6Y	LowPressure	3,11
0231_6Z	LowPressure	1,94

Figure 14: Seat post accelerometer X, Y and Z – overall analysis.

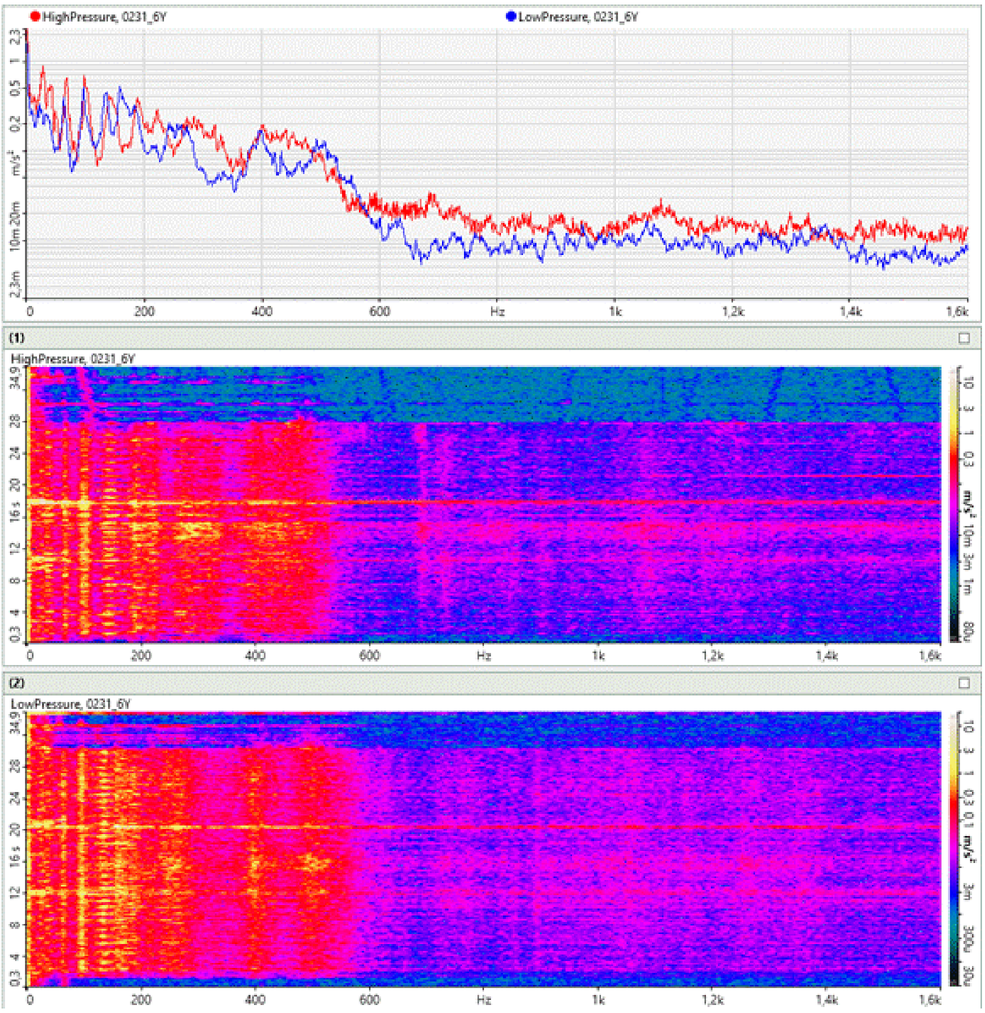

Figure 15: Wheel accelerometer Y direction, FFT and FFT vs Time.

Following the same analytical approach mentioned above, Figure 15 presents the frequency-domain results, this time focused on the Y-axis of the accelerometer positioned on the wheel. This analysis is conducted once again using both standard FFT and FFT vs. Time.

3.2 ODS Analysis

Operational Deflection Shapes (ODS) analysis allows engineers to understand the vibrational patterns of the test object under real operating conditions n.

This section illustrates how data from the Molecu sensors can be used for ODS. It is important to emphasize that this was only a preliminary analysis (pre-analysis) conducted to demonstrate the versatility and capabilities of the Molecu wireless sensors.

The ODS analysis was performed in the time domain to visualize the overall motion of a structure as it vibrates over a specific period. Time-domain ODS animates the combined motion resulting from all frequencies simultaneously; it allows you to visualize how the shockwave travels through the structure from the point of impact and helps reveal the relative movement between different components during a full operational cycle. This makes it possible to identify clearances, interferences, or misalignment issues that are not tied to a single frequency. Figure 16 presents the results of the ODS analysis. The figure displays the raw time-domain data for each sensor, alongside a simplified bicycle-frame geometry, illustrating both the overall structural motion and the movement of each individual point (node). To simplify the geometric model and streamline the analysis, the wheels were excluded, focusing the evaluation solely on the frame structure.

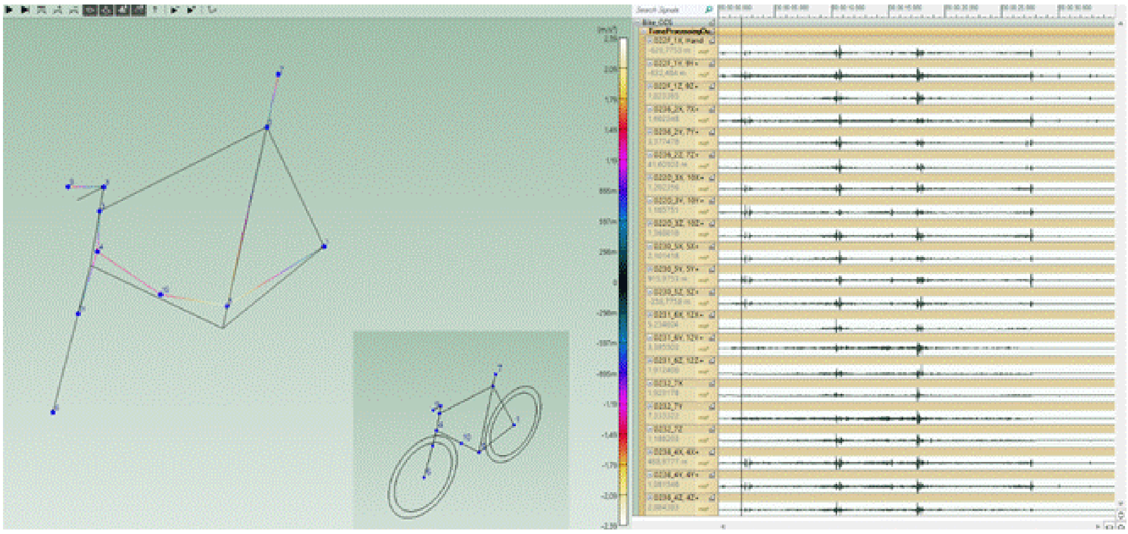

Figure 16: Time ODS of the bicycle frame.

3.3 OMA Analysis

Operational Modal Analysis (OMA) is a technique used to identify the dynamic properties of a structure, namely its natural frequencies, damping, and mode shapes, using only the vibration data measured while the structure is operating under normal conditions. The wireless setup makes instrumentation significantly faster, easier, and more easily adaptable to different types of structures. To demonstrate this capability, we performed an illustrative OMA. The sensor data is linked to a simplified test object geometry created for this purpose, and using both frequency-domain and time-domain OMA algorithms, we conducted a modal identification to showcase the feasibility of using wireless sensors for these types of measurements.

Figure 17 shows a stabilization diagram, the graphical tool used to distinguish true physical vibration modes from spurious, mathematical ones. Three natural vibration modes were successfully extracted. Figure 18 compares the modes identified through different OMA methods and provides the Modal Assurance Criterion (MAC) results for these modes.

The MAC is a statistical indicator used to quantify the degree of correlation, or similarity, between mode shapes. A MAC value close to 1 indicates that two mode shapes are highly consistent and likely represent the same physical mode, whereas a MAC value close to 0 indicates that the mode shapes are completely different.

This initial assessment validates the approach and paves the way for a detailed modal analysis of the frame in future studies.

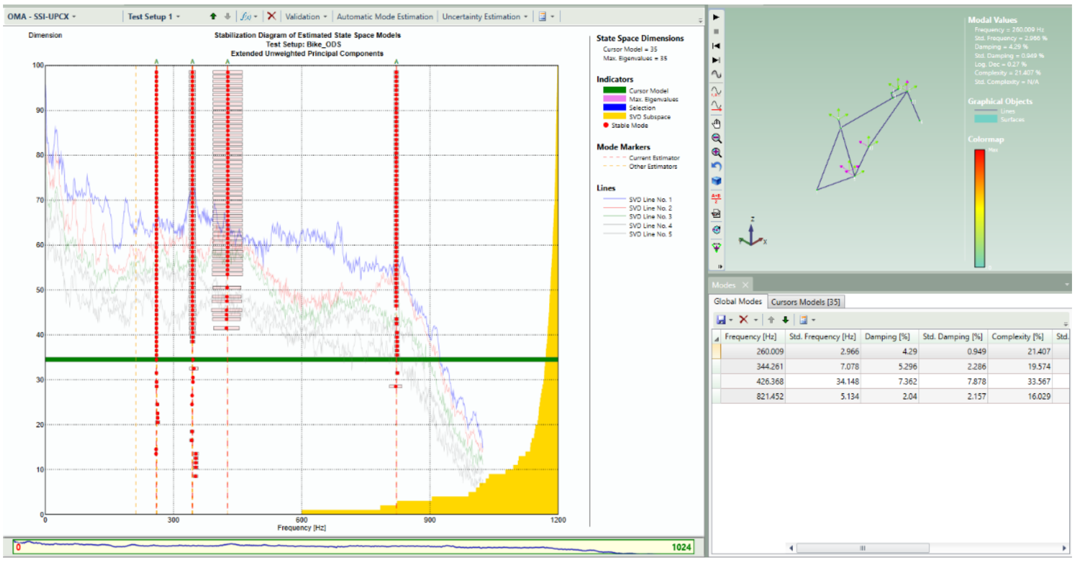

Figure 17: OMA stabilization diagram SSI-PC.

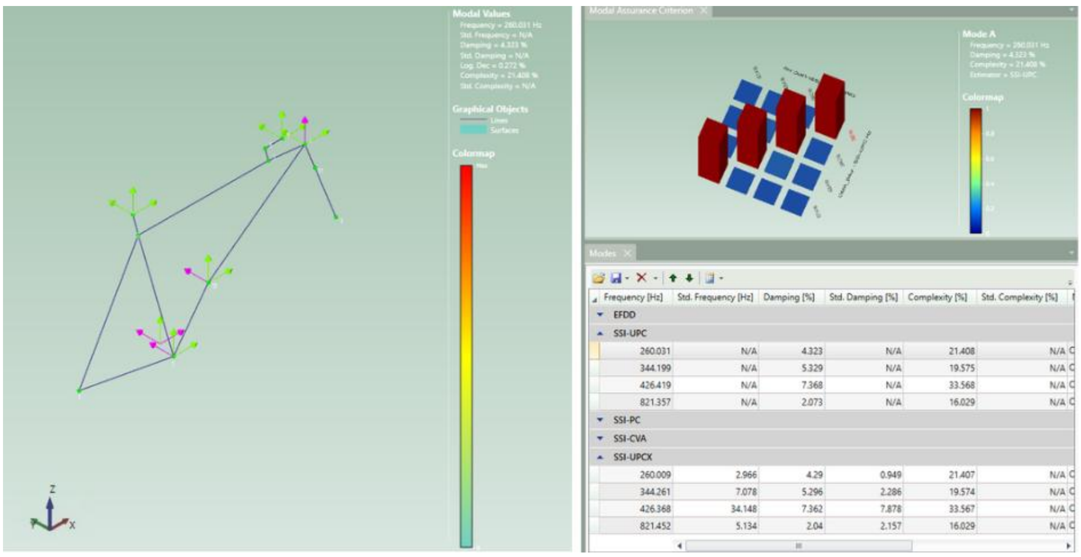

Figure 18: OMA mode shape SSI-PC vs SSI-UPCX and MAC.

4. Conclusion

This paper presents the use of MEMS-based wireless accelerometers for conducting vibration measurements on a bicycle. The analysis and results demonstrate that these accelerometers provide results comparable to those obtained using conventional wired accelerometers. However, wireless accelerometers offer clear advantages: they can be used in difficult or even inaccessible locations, such as rotating components. Their low overall system weight also enables measurements on lightweight structures such as drones. In addition, setup time is significantly reduced because no cabling is required

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