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THE IMPORTANCE OF HIGH-SENSITIVITY DISPLACEMENT DETECTION DURING VIDEO-BASED VIBRATION ANALYSIS

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ABSTRACT: Several decades ago, multiple channel FFT analyzers enabled the process of detection and animated plotting of vibrating motion. This included animating natural frequency mode shapes, as well as Operating Deflection Shape (ODS) determination. These have been important tools in visualizing the vibration of a machine and its system, including for example the foundation and piping networks. The input for mode shapes or ODS is the phase-linked signal set from a group of accelerometers, moved over often hundreds of test points. The data is superimposed onto a CAD model, and then scaled-up vibrations are animated at frequencies of interest. This process provides valuable insights, but is time-consuming and therefore expensive each time it is applied by experts, and it is error-prone.

An alternative method has been developed during the last two decades that is based on evaluation of high resolution/ high speed videos. The method provides information equivalent to a high-sensor-count mode shape or ODS, by treating each video pixel as an accelerometer, using the pixel's light intensity modulation to translate information embedded in the video into vibration motion able to be observed and interpreted by human investigators. This method is known by some investigators (e.g. Ref. 2, 3, and 4) as Motion Magnified Video (MMV), or sometimes also Vibration Video Amplification (VVA). It is much faster and less prone to interpretation error than accelerometer-data-based modal and ODS animations. However, it is displacement based, and displacements are extremely small for even significant vibration levels when the vibration frequencies are high (e.g. above 100 Hz), or when modal test impact energy cannot excite large displacements.

There are means to achieve useful results in spite of this challenge, as will be discussed in the current paper.

KEY WORDS: Motion Magnification; measurement accuracy; rotating machinery; machinery diagnostics; Vibration Video Amplification

INTRODUCTION:

High-sensitivity displacement detection during video-based vibration analysis is an important concept that is often overlooked by analysts. This work reviews the background of video-based vibration analysis, which the authors initially presented in their previous work relating to accuracy of data obtained from such systems [1]. In the present paper, the authors revisit research data of that previous work, present some new results, and offer further explanation to the practical importance of displacement sensitivity in video-based vibration evaluation.

Rotating and reciprocating machinery vibration is often useful in determining whether or not a machine is operating properly, and for diagnosis of problems if the operation appears improper. If reliability issues have been experienced (e.g. fatigue cracking, or premature failure of bearings and seals), vibration can provide important clues concerning the root cause.

For several decades, visual methods have animated a CAD model to exhibit operating deflection shapes (ODS) of vibration in an understandable manner. This has been an important tool in getting a complete and simultaneous view of the vibration of the machine and its system (e.g. piping, foundation, and driver as well as driven machine), so that the source and potential importance of any given vibration mode is placed in proper context. The resulting animations represent the motion consistent with phase-linked signal spectra from a group of accelerometers. To provide representative and comprehensive results, such accelerometers typically need to be located over hundreds of test points, providing data in 3 orthogonal directions. Following the data acquisition, the exaggerated (i.e. scaled-up to a visually useful level) vibrations can be animated as "cartoons" at frequencies where the response is sufficient to be of interest to a person evaluating and troubleshooting the machine. This process may take one or more days to perform properly for complex machinery and associated systems.

An innovative vibration detection and display method named Motion Magnification Video, or MMV (or sometimes Video Vibration Analysis, or VVA) has been developed by several independent groups. Each group's approach has a different algorithm at its core, but all are based on evaluation of high resolution/ high speed video taken of the vibrating system, such as operating machinery. These MMV methods can provide information equivalent to a high-sensor-count ODS test. Several methods, including that of the authors, do this by treating each pixel in a video scene as an accelerometer, using the pixel light intensity modulation statistics to determine the local vibration displacement motion as a function of time and frequency. From this information, realistic magnification of slow-motion video footage permits microscopic vibration to be magnified, and thereby observed and interpreted by the human troubleshooter. Just as with accelerometer outputs, the pixel time series statistics can be Fourier transformed to determine frequency spectra as well. The MMV-based vibration display method is much faster than classical ODS, yet provides similar information at many more locations (at least in directions within the 2-D field of view), with less opportunity for human error. The result is more credible to both technical as well as non-technical decision makers because they are looking at the amplified motion of the actual machine or structure. However, use of MMV at high frequencies, or in other situations where even excessive vibration displacements (according to standards such as ISO) are very low, has been an ongoing challenge for commercially available MMV/VVA systems. This is particularly true when lower capability/ lower cost camera equipment is implemented.

BACKGROUND- CLASSICAL VIBRATION VISUALIZATION METHODS:

About 1980, some researchers developed a methodology for "seeing" vibration in extensive mechanical systems. Their approach was to acquire data at many locations and directions on a vibrating structure, and then allocating those motions to a stick-figure CAD model. This model was then animated on a computer video screen, or the extreme motion was printed in a still frame. The resulting Operating Deflection Shape (ODS) method has proven very powerful, but is time-consuming, and therefore expensive, to implement in any detail. It is also prone to user error, with regard to book-keeping the sensor locations and directions, and accurate construction of the cartoon model that these are applied to.

VIBRATION VIDEO AMPLIFICATION (VVA) METHODS:

Many of the ODS drawbacks can be avoided if an actual visual scene is able to be evaluated concerning the vibration of components within the scene. Academic researchers, some of whom are listed in the References [2], [3], and [4], had this thought as much as 30 years ago, and have been gradually perfecting techniques. Basically, these techniques fall into two categories: 1) tracking of specific points, edges, or (as machine-vision scientists call them) "blobs", and 2) performing statistics, including signal vs. time as well as signal FFT frequency spectra, on the individual independent pixels. The former are called "Lagrangian Methods" by many researchers, and the latter are called "Eulerian Methods". A rich literature basis exists for these methods. This paper's limited references emphasize the Eulerian technique pioneered by researchers at the Massachusetts Institute of Technology (MIT), and named by them as "Motion Magnification".

The Motion Magnification Video (MMV) method of this present paper may be summarized as follows:

- Uses high-speed, high-resolution video
  - Eulerian method is equivalent of millions of accelerometers, 1 per pixel
- Analyzes/quantifies displacement motion, in 2-D and implied 3-D
  - FFT can be used to separate motion into individual frequencies
- Algorithms amplify motion to at least the human visual threshold
  - Filterable by desired frequencies, high resolution (up to 4+ kHz in the system as presented by the authors).
  - Amplifies up to 1000+ times the actual motion, using a statistical algorithm that can perceive and magnify motions down to less than 0.1% of pixel.

HISTORY:

Various researchers, in the US as well as Europe, have developed a variety of video acquisition and evaluation processes to study other dynamic phenomena. In fluid dynamics, laser-doppler velocimetry (LDV) has been able to track streamlines, and similar processes have been applied to mechanical vibration. In a lower-tech method, strobe lights have been used on machinery for many decades to "freeze" motion at a given frequency. These methods have been useful for interpreting dynamic behavior if relatively large motions are involved.

In the 1920's, advanced research organizations used relatively high-speed cinematography to guide development and to evaluate the validity of new vibration analysis procedures. A good example is the work of Wilfred Campbell at GE. At the time, steam turbines driving generators were growing larger, and as they did, they encountered unexplained fatigue failures. Campbell's work, as exemplified by the photo in Figure 1 (a single frame of a "movie" or framed video taken by his cameras), determined that bladed disks had much more complicated natural frequency mode shapes and resonant vibration behavior than had been predicted up to that time, including zero-vibration nodal lines in their mode shapes, now known among turbomachinery engineers as nodal diameters and nodal circles. When a natural frequency matched a strong excitation frequency (such as the number of stator nozzles times running speed), and when simultaneously the mode shape of the natural frequency matched the lobes of a circumferential pressure pattern (such as associated with the number of blades versus number of stator nozzles), a strong resonant response was seen to occur. This caused fatigue in many cases.

Based on this insight, GE and eventually others were able to avoid damaging resonances by either adjusting natural frequencies, or by adjusting problematic lobe patterns and/ or frequencies of the nozzle pass excitation frequency. The Campbell Diagram, now well known to turbomachinery engineers, became a graphical method of codifying this procedure.

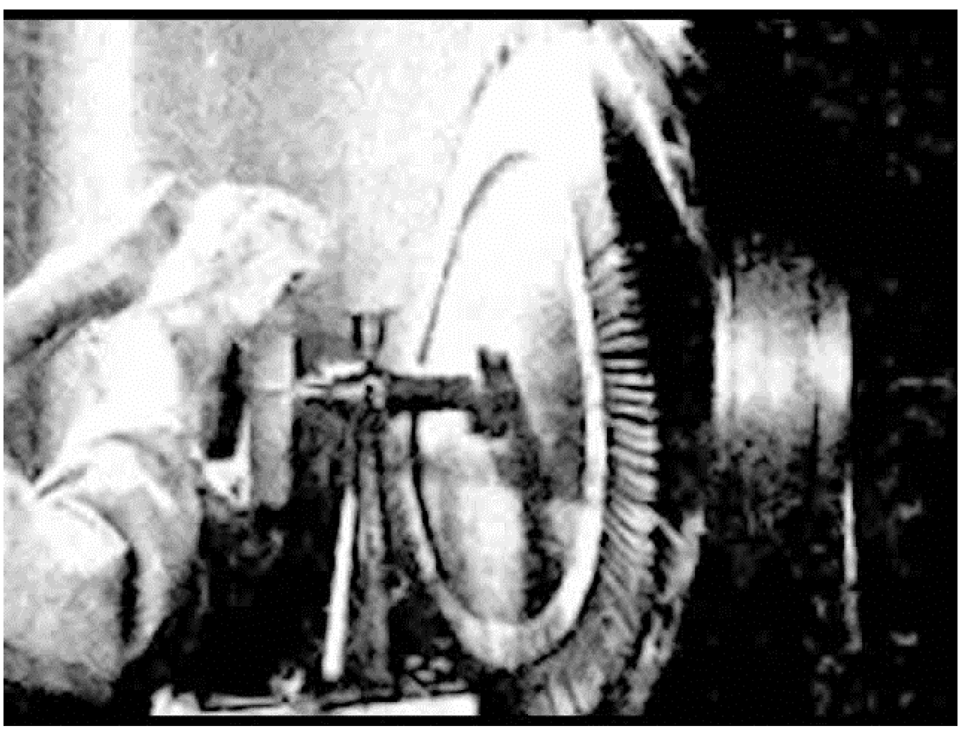

Figure 1: Campbell's bladed disk video from 1924

Such successful efforts led later scientists and engineers to an appreciation for the power of video to uncover useful dynamic information in dynamic scenes, assuming that appropriate algorithms, implemented by software, were implemented to evaluate the video footage.

Several universities, including MIT [2], [3] as discussed, have been actively pursuing MMV. At MIT, the particular technology that became the core of their research was initiated in the mid-1990's. It represents an Eulerian approach [4], which tracks the variation of individual pixels over time, and then exaggerates any changes.

To the human eye, no matter how long and hard a person stares at a machine with vibration at, say, several times the velocity level of ISO machinery acceptance limits, a person would struggle to detect any motion. For a computer, however, the tiniest per-pixel fluctuations (between white and slightly-off-white, say) are easy to detect and quantify. MIT originally developed their Motion Magnification software approach to measure the vital signs of neonatal babies without physical contact, but they realized that there were other far-ranging applications. For biological applications, Eulerian MMV detects and exaggerates changes in skin color, as well as exaggerates breathing movements.

PAST HIGH-SPEED VIDEO RESEARCH BY THE AUTHORS:
The authors' organization initiated its detailed research into engineering uses for high-speed video in 2003. The US Department of Defense contracted the authors' group to study how to make non-lethal projectiles operate reliably, ensuring that they functioned without harming humans or animals. Applications included various forms of "soft bullets". High speed video, up to 20,000 frames per second, documented their transient behavior during flight and impact.

A later application (2005) involved an inexpensive video sensor to feed pattern recognition software to rapidly identify rocket-propelled grenades (RPGs) fired by a belligerent, so that defensive steps could be taken to save an aircraft or vehicle. Following this was use (2011) of high-speed video to determine the moment-to-moment effectiveness of passive counter-measures to fool MANPADS missiles fired by adversaries to bring down (for example) an airliner, providing feedback facilitating improved countermeasure design. More recently (2015 to present), the authors' group was contracted to use high-speed video and pattern recognition to rapidly characterize lethal ranges of various munition types, so that friendly military forces are better able to ensure sufficient buffer zones for civilians, schools, and hospitals in war zones. In 2018 a high-speed video system was developed to study the dynamics of jet aircraft ejection seats, as evaluated with tracked rocket sleds.

During this process, the authors began applying Eulerian algorithms to measure and amplify motions of individual pixels [5]. Different procedures were tried during both government and IRAD-funded testing, and after several years a successful method was achieved. Transient motions and vibration levels as low as two tenths of a mil (i.e. 5 microns) on machinery surfaces were demonstrated first in the laboratory, and soon after in on-site machinery troubleshooting. Recently, there have been considerable improvements in accuracy, as will be discussed.

As presented above, the authors' methods are based on the Eulerian approach [2], [3], [4], and [6], which observes the intensity variation of individual pixels, combining their effects statistically into a full scene. Alternative methods [7] typically keep track of motion pixel-to-pixel, the so-called Lagrangian techniques. Variations include feature tracking, and an approach called "optical flow". These Lagrangian methods are good for amplifying motions that occur over multiple pixels, e.g. motions of more than 2mm (0.080 inches) for a 3 m (10 foot) field-of-view. However, these approaches are limited in how small a displacement they can detect for a given field of view and a given camera resolution, in that vibration levels of interest can be well below such limits, particularly at higher frequencies of vibration. If higher camera resolutions are used to overcome this limitation, the computational overhead becomes excessive due to the mega pixel count. One competing application mediates this by selecting only a greatly reduced number of pixels in a scene, and using these as the basis for evaluation and animation.

The benefits of MMV performed for vibration testing are that it becomes a powerful and intuitive procedure for displaying complex patterns and vibrating shapes in a relatively short time-frame. It realistically animates modes of vibration in a manner that is easy for non-experts to believe and understand. Importantly for certain applications, the technique does not require contact, so that surfaces above 1000 F, or that are radioactive, or that are (for example) 50or 100 feet vertically above in a ceiling or a tower, can be observed without difficulty. Furthermore, items such as machinery instrumentation wires or lubrication lines, which would change their behavior if mass-loaded with even a small accelerometer, can be evaluated in a manner that does not alter their behavior. The results are obtained quickly, and at modest cost and effort.

However, there are several potential problems in applying MMV to vibration motion detection and display. The primary issue is whether displacement detection is sufficiently accurate and reliable, and possesses a low enough detection threshold. A short discussion of a math example illustrates this. Based on the physics and with proper units conversion:

$$V \text{ (in/sec rms)} = 0.00222 \times \text{frequency (Hz)} \times \text{Displacement (mils p-p)}$$

Applying this formula, for an example frequency of 500 Hz, 0.020 mils p-p (i.e. 20 millionths of an inch), as demonstrated routinely by the authors' research, translates into 0.022 ips rms, very adequate accuracy for comparison of vibration to standards such as ISO.

However, 1 mil p-p (as is the typical limitation for some systems) translates into 1.1 ips rms, clearly not acceptable for detecting potentially serious vibrations, since it is well in excess of standards. Figure 2 illustrates the displacement vs. frequency issue over a broad practical range of interest for machinery assessment, based on the ISO 10816-3 industrial machinery vibration standard, and postulated accuracies of 0.1 mils p-p to 1.4 mils p-p.

Eulerian methods have been shown to work better than competing methods for detection of small displacements, and motion detection below 1/2000th of a pixel have been demonstrated [5]. When enhanced by frame-triggered synchronous averaging, the authors have achieved results superior to this.

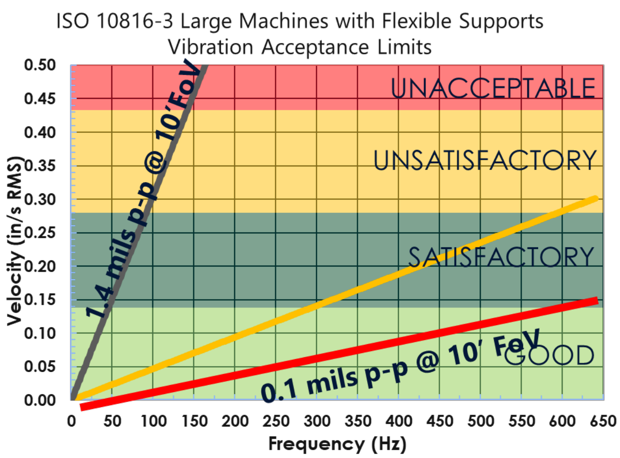

Figure 2: Relationship of Vibration Velocity vs. Displacement and Frequency [8]

The concept of triggered synchronous averaging is an averaging-by-vector-summing process that is performed for many data sets taken of a consistent vibration pattern, as represented by the output of various vibration detection sensors (usually accelerometers when MMV is not being implemented).

In the case of MMV, the authors have accomplished this by a proprietary approach involving multiple synchronized video clips being trigger-synchronized and "averaged" together. This:

- Reduces level of vibration not consistent with the trigger
- Reduces camera sensor white noise effects
- Lowers vibration detection threshold for the same duration video
- Enables use of lower cost camera equipment

RECENT RESEARCH RESULTS:
MMV accuracy testing has been performed by the authors using the experimental set-up shown in Figure 3:

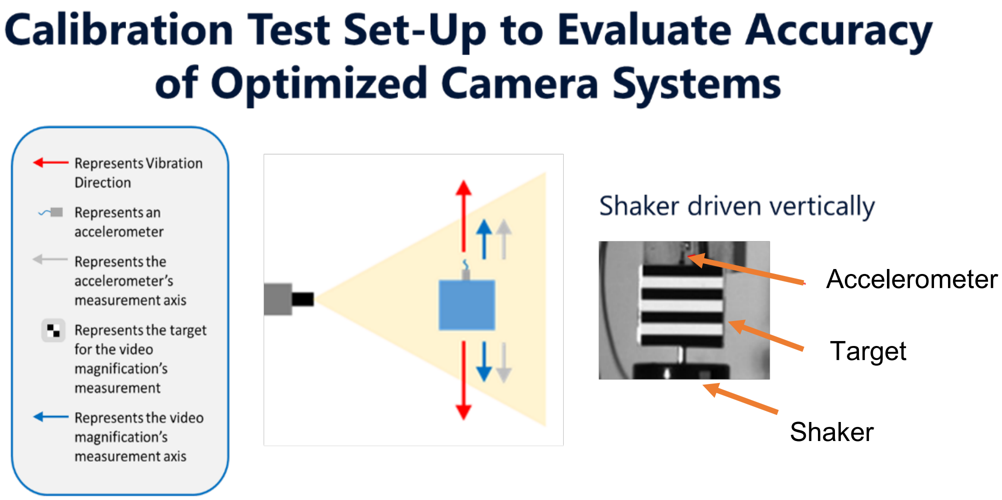

Figure 3: Accuracy calibration test set-up. Certain tests used proximity probes or a laser vibrometer in place of, or in addition to, the accelerometer.

The authors' research has shown that accuracy of detection during MMV depends strongly on the following issues:

1. **Hardware**
   - Low sensor noise and good exposure control is required, needing cameras of at least moderate expense.
   - High bit depth of sensor ("dynamic range") is required, again needing moderate expense cameras for good displacement resolution.
   - Screen resolution: This is no longer such a big issue with most magnification algorithms (such as [2] and [3]), so moderate or even less expensive cameras are acceptable in this regard.

2. **Acquisition**
   - Always a function of the field-of-view. The authors recommend evaluating competing systems based on a 3 m (10 foot) field-of-view, for applicability to typical plant rotating machinery (and associated pertinent systems) of interest.
   - Illumination level, contrast, and ability to deal with flicker of lighting.
   - Focus/edge definition, shutter and exposure control.
   - Steadiness (shaky tripod).
   - Sufficient frame rate for the maximum frequency desired. Nyquist requires at least a frame rate/max frequency ratio of 2. Higher frame rate is desirable.

3. **Software**
   - Proprietary methodologies are different from vendor-to-vendor. Simplicity and user-friendly interface are important, but ensure a sufficiently low displacement detection threshold, consistent with the plant's equipment and applicable standards. Ability to detect under 0.1 mils p-p (2.5 microns p-p) at a 10 foot (3m) field-of-view is recommended for machinery diagnostics, based on the authors' experience.

Figures 4 through 8 show representative results from the authors' research, in each case based on video taken using the optimized approach developed by the authors, but without the implementation of signal averaging.

Figures 4 and 5 show that frame rate effects, or more precisely frequency as a percentage of frame rate, also have influence, with poorer accuracy associated with higher frequency / camera half frame rate ratios. In addition to the latter, higher frequency has an inherently large practical effect on amplitude accuracy for a given vibration velocity, as illustrated in Fig. 2.

Figure 6 shows that, as displacement becomes lower, the error associated with the measurement becomes (as expected) worse. This becomes a particular problem as frame rate approaches the Nyquist limit (i.e. frequency divided by half frame rate = 1), especially as displacement lowers toward 0.1 mils p-p. Fig. 7 shows that at low displacement amplitudes, accuracy is even more sensitive to the ratio of frame rate of the camera vs. frequency of interest, with a low ratio being a challenge as it approaches the Nyquist frequency ratio of 2, particularly if the camera is constructed for high frequency video acquisition. This situation can be improved if special approaches are used, such as shutter control trigger timing and time-averaging of the video frame acquisition as discussed. Error from the camera sensor noise floor also statistically becomes less of an issue with time-averaging.

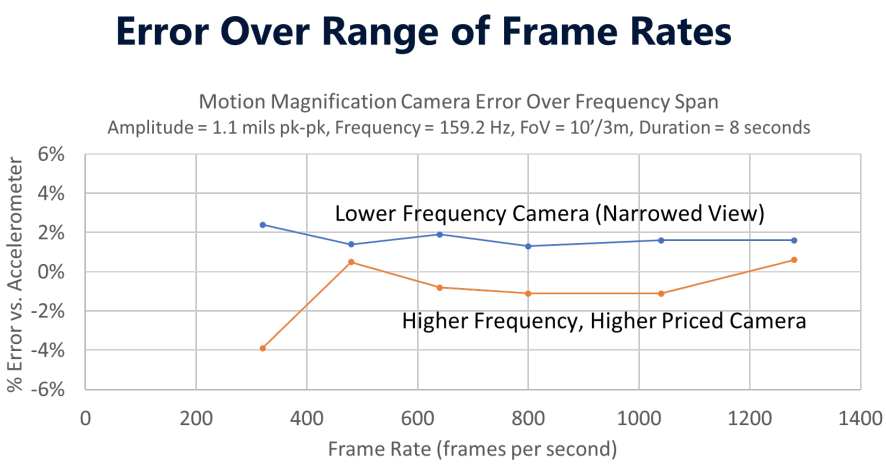

Figure 4: Accuracy test results showing error versus camera frame rate

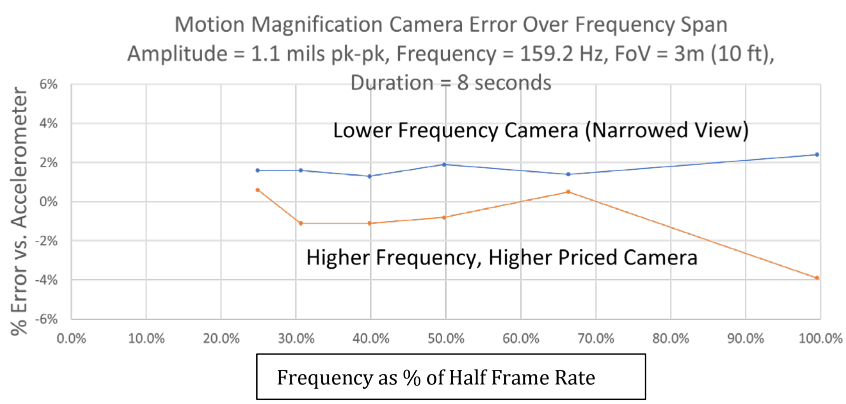

Figure 5: Accuracy test results showing vibration amplitude error vs frequency as percent of half frame rate.

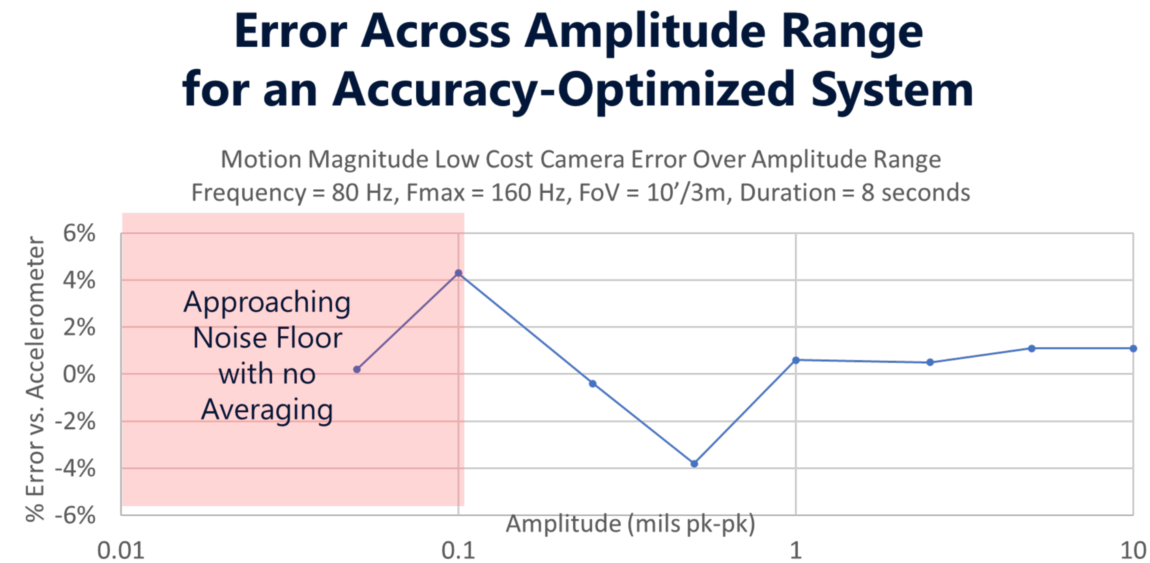

Figure 6: Accuracy test results showing error in detected vibration vs. amplitude.

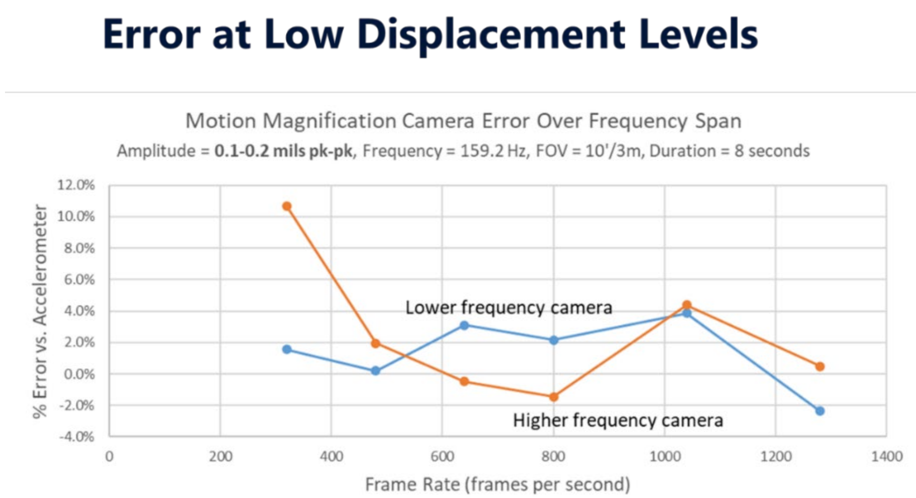

Figure 7: Accuracy test results showing error versus frame rate for lower vibration levels

The data of Fig. 8 demonstrates a similar situation for detection threshold as exists for the detection accuracy (error) presented in Figs. 4-7. Detection accuracy and threshold are not the same. Accuracy relates to the precision and correctness with which the system is able to represent a given vibration amplitude. On the other hand, the threshold denotes the smallest displacement that can be reliably distinguished from noise. The latter is particularly important in order to detect acceptably small velocity levels at high frequency, as demonstrated in Fig. 2 earlier. Note that threshold, similar to accuracy, improves for increases in video duration time and/ or frame rate. It can also be improved significantly by frame-synchronized averaging.

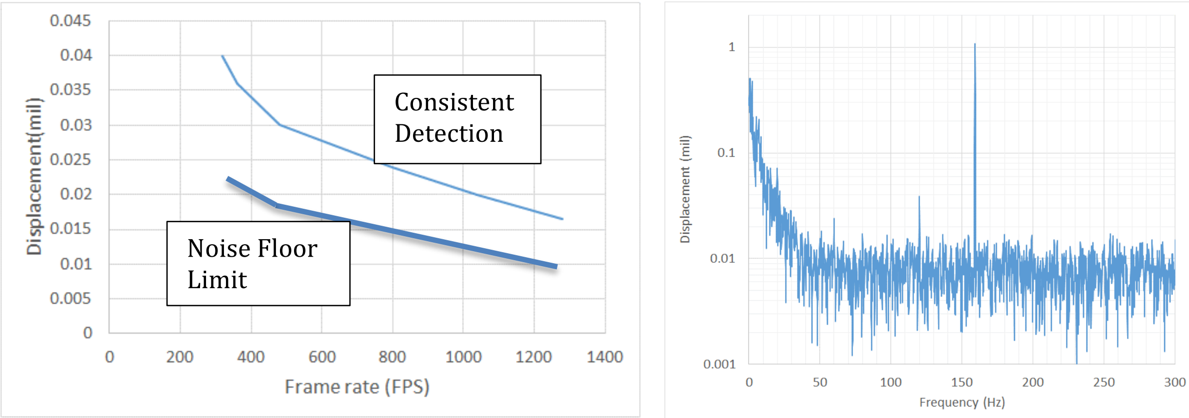

Figure 8: Example of displacement detection threshold (i.e. displacement at which signal-to-noise ratio = 1.0) for the MMV/vibration video amplification system developed by the authors. For both plots, Field-of-View = 10 feet (3 m), and test specimen displacement amplitude = 1 mil (25.4 microns) p-p. For the data on the left, narrowband frequency = 159.2 Hz. For data on the right, frame rate = 1280 fps. Note that this data was obtained without the benefit of synchronized time-averaging.

A summary of the accuracy and detection threshold experienced by the authors during their research is as follows:

- With no accuracy optimization, author's experience was +/-35% error
- Recent research using advanced techniques achieved an accuracy within +/-4%
- Accuracy depends on the camera hardware, lighting, and algorithms used
- Best accuracy and detection threshold are achieved with higher frame rates, longer data acquisition times, adequate frame rate and dynamic range, good exposure control, and good lighting
- Considerably better accuracy and detection threshold are achievable with the aid of averaging carefully synchronized with the camera shutter for a given frame rate.

PRACTICAL APPLICATION:

In practical situations, such as working at a plant, environmental conditions can vary and consequently affect the data. Key factors include ambient lighting, access to target, ground vibrations being transmitted through the tripod and to the camera, and user ability to focus the camera in full sun conditions. These factors can be controlled to an extent, but can negatively affect detection threshold and accuracy of video vibration systems. Also, since detection threshold and accuracy depend also on specifications built into the MMV system (e.g. hardware and software), it is important to consider the MMV system specifications, which are usually defined in an ideal situation, and may not consider potential negative factors.

Interpreting the MMV system sensitivity from manufacturer specifications is not always straightforward, since any claimed sensitivity directly correlates to the field of view. For example, the ability of the MMV system to detect down to the detection threshold lines shown in Figure 2 were contemplated for a ten-foot (roughly 3 m) field of view. If the field of view of changes, for example, to five feet (roughly 1.5 m), then a given MMV system's detection threshold would be expected to improve by a factor of two.

This fact is important in field scenarios where it is desired to capture the entire system, supporting structure, and associated equipment. For example, consider a large rotating machine that the troubleshooter wishes to perform MMV vibration analysis on, such as a twenty foot (6m) long turbine, in order to capture the vibration and movement relationship from end to end. In this case a high sensitivity MMV system is essential, because at a twenty foot (6m) field of view the vibration detection threshold would worsen for typical systems from 0.1 mils/ 2.5 micron p-p (ten foot or 3 m field of view) to 0.2 mils/0.5 micron p-p (middle curve in Figure 2 plot).

The other aspect to understand in the use of MMV systems, in relationship to field-of-view, is that the optics (such as the lens and camera sensors, in combination with distance to target) affects the field-of-view. This means that detection threshold is highly dependent on how the particular shot is set up. Figure 9 below shows two examples of how lens selection combined with distance-to-target affect field of view, hence impacting the best-case vibration detection threshold achievable with the camera sensors.

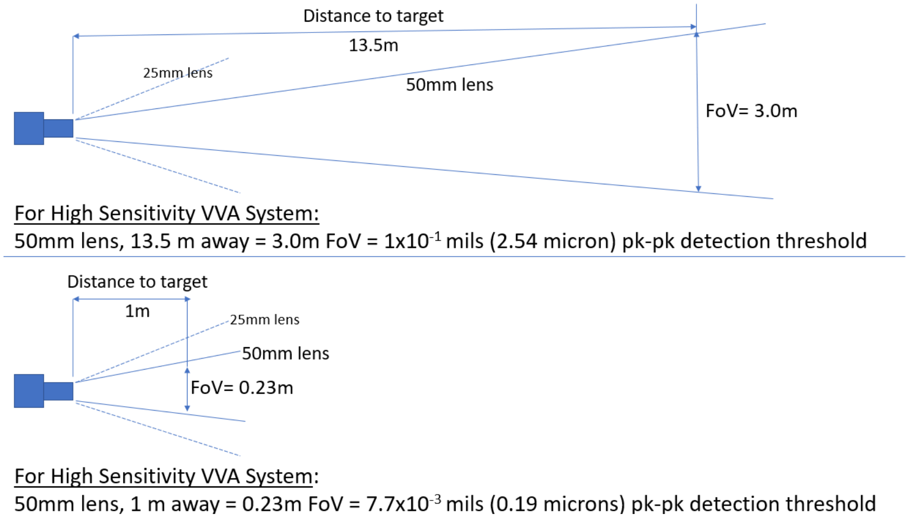

Figure 9. Comparison of how field-of-view affects MMV system vibration detection threshold, by changing distance to target, for example MMV system with 0.1 mils p-p detection for 3m field-of-view.

It is imperative for MMV analysts to understand these relationships, so they can select a system adequate to their practical needs, and can best set up and record video in a manner that achieves optimal results.

FUTURE RESEARCH:
The following summarizes the research currently underway at the authors' organization:

1. Improving MMV detection capability and frequency range using low-cost COTS cameras
2. Continuous improvement of displacement sensing accuracy
3. Continuous improvement of practical upper frequency limit
4. Acquiring ODS (including torsional) vibrational motion of rotating components
5. Processing and displaying 3-D vibration patterns
6. Use of MMV related technology to detect and display alignment of driver vs. driven machines
7. Continue MMV system accuracy and detection threshold enhancement through use of precision synchronous averaging.

CONCLUSION:
The video-based vibration amplification procedures and equipment presently on the market can be very useful for determining and displaying vibration behavior of rotating machinery and associated piping and systems. The enhanced Eulerian method discussed in this paper has advantages over conventional MMV, and is superior (or at least worthy to be supplemental) to traditional measurement methods in many instances. MMV methods typically take much less time and "logistics" than conventional detailed vibration testing, such as ODS methods, to implement. Primary conclusions of this research include:

1. Detection accuracy & threshold of conventional video vibration analysis systems is often insufficient, if used to detect vibration levels relevant to typical standards (e.g. ISO-10816-3), in a full field-of-view.

2. Detection accuracy & threshold is a complicated function of many factors, including (but not limited to) camera quality, software algorithm functionality, and video-taking technique.
3. Camera dynamic range and "noise floor" is also key (this may be a challenge in cell phones).
4. An inherent and primary factor affecting minimum detectable vibration velocity level is the maximum frequency to be detected.
5. Other important factors include frame rate, lighting, exposure control, and surface or target contrast.
6. Frame-triggered synchronous averaging has been found to offer significant improvement in accuracy, and ability to tolerate use of less expensive cameras.
7. The accuracy and detection threshold of MMV systems will depend strongly on the core algorithm design.

If procedures are used to achieve sufficiently accurate and minimized displacement detection, MMV can reliably determine behavior for vibration levels relevant to international standards such as ISO, even at significantly high frequencies. As such, MMV presents an important addition to a vibration diagnostic tool kit.

REFERENCES:

[1] Lerche, A.H., Marscher, W.D., Frolov, S.V., "What drives accuracy for video vibration?", COMADEM International Journal of Condition Monitoring and Diagnostic Engineering Management, vol 27, issue 2, p7 (award winning paper at MFPT2023), c. 2024

[2] Timoner, S.J., and Freeman, D.M., "Multi-image gradient-based algorithms for motion estimation", Optical Engineering 40.9, pp. 2003-2016, c. 2021

[3] Liu et al, "Motion magnification", ACM Transactions of Graphics (TOG) – Proc. of ACM SIGGRAPH 2005, TOG Homepage, v. 24, Issue 3, July 2025

[4] Wu, H-Y et al, "Eulerian video magnification for revealing subtle changes in the world", ACM Trans. of Graphics (Proc. SIGGRAPH 2012), v. 31, August 2012

[5] Marscher, W.D., and Onari, M.M., Video Motion Magnification vs. Operating Deflection Shapes for Machinery Diagnosis, MFPT2018, Virginia Beach, May 2018

[6] Chen, J.G.; Davis, A,; Wadhwa, N; Durand, F; Freemans, W.T.; and Oral Büyüköztürk, O., Video Camera–Based Vibration Measurement for Civil Infrastructure Applications, ASCE JIS, 2016

[7] Diamond, D., Oberholster, A., Heyns, S., Structural Vibration Field Test Using Optical Flow Analysis of a Video Sequence, Proc. AIP Conf., 2016

[8] ISO 10816-3-2018, Mechanical vibration - Evaluation of machine vibration by measurements on non-rotating parts - Part 3: Industrial machines with nominal power above 15 kW …, International Standards Organization, Geneva Switzerland, c. 2018

[9] Lerche, A.H., and Marscher, W.D., "Comparison of ODS and Motion Amplified Video Techniques", 89th Shock and Vibration Symposium, Dallas TX, Nov. 4-8, 2018