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Post-Processing ODS Data from a Vibration Video

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ABSTRACT

Over the past 20 years, Optical Flow algorithms have been developed for extracting dynamic features and time waveforms from a video recording. Optical Flow algorithms are now being used in many new applications, including autonomous vehicles and robots that employ machine vision.

In this paper, one of those algorithms is used to extract time waveforms from video recordings of vibrating machines & structures. It is shown how these time waveforms can be post-processed and a new video created that makes it possible to visualize the Operating Deflection Shape (ODS) of a machine or structure within a few minutes of recording the original video.

Multiple time waveforms taken from a vibration video recording constitute a ***set of time-based ODS's***. In this paper, a new approach is presented for post-processing a set of time-based ODS'***s*** to create a new ODS video. An ODS video can be created either by sweeping a cursor through the time-based ODS's and deforming a rectangular surface with the ODS from each sample of the time waveforms, or by placing a cursor at a resonance peak in a ***set of frequency-based ODS's*** and using sinusoidal modulation to deform the surface.

This new approach has several unique advantages; 1) control of the animation ***speed & amplitude*** to provide much clearer visualization of the vibration, 2) use of the ***original video color graphics*** thus making the new video more realistic, 3) ***color contours*** superimposed on the video to indicate levels of vibration, 4) display of the ***frequency-based ODS*** at any frequency in the original video data, 5) display of the ***magnitude & phase*** of the ODS at key points on the test article. 6) removal of ***camera jitter & background noise***.

Examples of these unique advantages are discussed and presented in this paper.

KEY WORDS

Operating Deflection Shape (ODS)
Time-Based ODS
Frequency-Based ODS
Linear spectrum (FFT)
Cross spectrum (XPS)
Frequency Response Function (FRF)
Transmissibility (TRN)
ODS FRF

INTRODUCTION

Troubleshooting structure-born noise and vibration problems is a much-needed application for ODS videos. When a machine or structure undergoes excessive or sustained levels of vibration, material or system failure is the inevitable result.

The vibration of any mechanical system or structure is closely related to its physical properties (its mass, stiffness & damping). In fact, its vibration is ***very sensitive*** to changes in its physical properties. If any physical property changes, the structure will vibrate differently. Also, if any boundary condition (loose mounting for example) changes, the structure will vibrate differently

Prior to the use of vibration video recordings, the most popular method for making an ODS video required that sensors (typically accelerometers) be attached to the surface of the structure to record its vibration. Non-contacting sensors such as laser vibrometers, optical sensors, and microphones have also been used to measure surface vibration. All of these methods are more expensive and time consuming than recording a video, and their use may even be prohibitive in some cases where recording a video is still possible.

MEASURING VIBRATION

Vibration is typically measured either by attaching vibration sensors to the surface of the structure, or by measuring its surface motion with a non-contacting sensor such as a laser vibrometer. In this paper, a video recording of the surface vibration is used to provide the vibration data.

Regardless of the type of sensors used; all vibration is initially captured as a series of time waveforms.

In a vibration video recording, the color change of each pixel between successive video frames is used to create a time waveform for each pixel. These waveforms are assumed to carry in them all the vibratory motion of surfaces on the structure in the field of view of the video.

Over the past 20 years, a variety of algorithms have been developed for extracting dynamic motion of surfaces from a video recording. We have found that one algorithm (developed by Gunnar Farneback [1], [2]) provides ***accurate time waveforms*** of surface vibration.

OPTICAL FLOW

Starting in 2000, Gunnar Farneback began publishing results of his research and development on Optical Flow. Reference [1] also includes several other references on this subject. Since then, Gunnar’s Optical Flow method has been implemented in software and is available to the public.

The website [2] contains videos that illustrate Optical Flow. Figure 1 shows one frame of a video containing the paths of cars on a highway obtained with an Optical Flow algorithm.

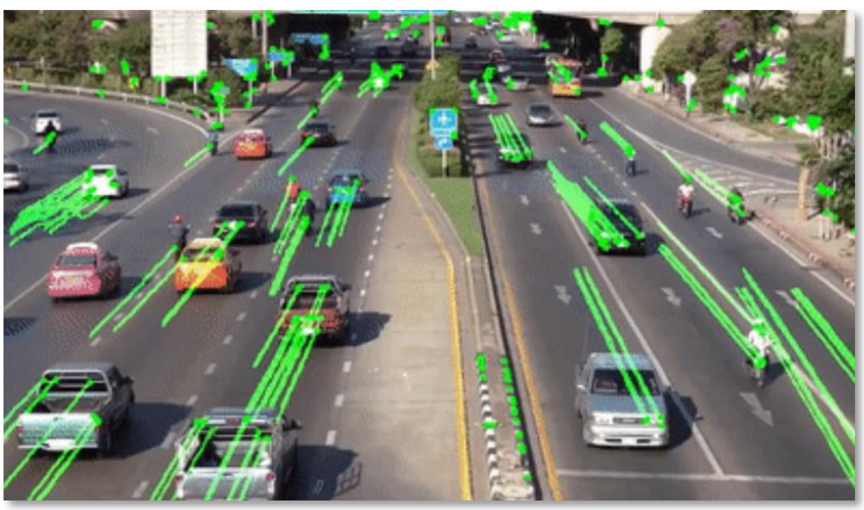

Figure 1. Optical Flow of Traffic on a Highway

GLOBAL SHUTTER CAMERA

We began this development by using an Optical Flow algorithm to extract time waveforms from vibration videos recorded with a camera that ***simultaneously samples*** each pixel in a frame. This is called a ***global shutter***. The Chronos camera shown in Figure 2 records videos using a global shutter.

Simultaneous sampling of all pixel colors in a frame is analogous to simultaneously sampling the sensor voltages of multiple channels of data using a multichannel acquisition system.

Two or more time waveforms that have been ***simultaneous sampled*** constitute a **set of time-based ODS's**. Simultaneous sampling of multiple time waveforms, whether from sensor voltages or from a video, guarantees that a resulting ODS will contain the ***correct relative phase*** in all its components.

Figure 2. Chronos Camera Used for recording Vibration Videos

ROLLING SHUTTER CAMERA

The alternative to a global shutter is called a rolling shutter. A camera that uses a rolling shutter samples the pixels one row at a time when recording a video. All lower-cost cameras use a rolling shutter, including the cameras in cell phones.

A rolling shutter is analogous to using a mux (fast electronic switch) which samples sensor voltages one at a time in a multichannel acquisition system.

A rolling shutter will create a ***phase difference*** in the time waveforms from the top to the bottom of each video frame. This will add phase to the ODS between the top & bottom of an ODS video. For low frequency ODS's, this phase error might be insignificant.

An example of post-processing a cell phone video is shown in Figure 5. The set of frequency-based ODS's used to create the animation contains ***9568 frequency spectra***.

The vibration video was recorded with a Sony Xperia XZ2 Compact cell phone. It records at 960fps and can record 91 frames of 1920x1080 resolution (Full HD) (0.09375 sec) or 177 frames (.183 sec) at 1280x720 resolution.

WHAT IS AN ODS?

An ODS is defined as the ***deflection of two or more points*** on a machine or structure.

Stated differently, an ODS is the deflection of one point relative to all others on a structure. Deflection is a vector quantity, meaning that it has both ***location & direction***. Deflection measured at a point in a specific direction is called a **DOF** (***Degree of Freedom***).

- An ODS can be defined from any vibration data, either at a ***moment in time***, or at ***a specific frequency***
- With calibration, an ODS can answer the question, ***"How much is the structure really deforming*** at a ***moment in time*** or ***at a frequency?"***

Time-Based ODS

- A time-based ODS is defined from ***two or more*** time waveforms at the ***same moment*** in time
- If ***two or more*** time waveforms are extracted from a ***single vibration video***, they are ***phase-matched*** time waveforms
- Two or more ***phase-matched*** time waveforms constitute a **set of time-based ODS's**
- A **single time-based ODS** is obtained at the ***same time sample*** in a **set of time-based ODS's**

A time-based ODS can be defined for any kind of vibration; e.g. random, impulsive, or cyclic. Sweeping a line cursor through a set of time-based ODS's reproduces the motion recorded with the vibration sensors, including a video.

The motion of a crane boom at one of its dominant frequencies is shown in Figure 3. The set of time-based ODS's used to create the animation contains ***9800 time waveforms***.

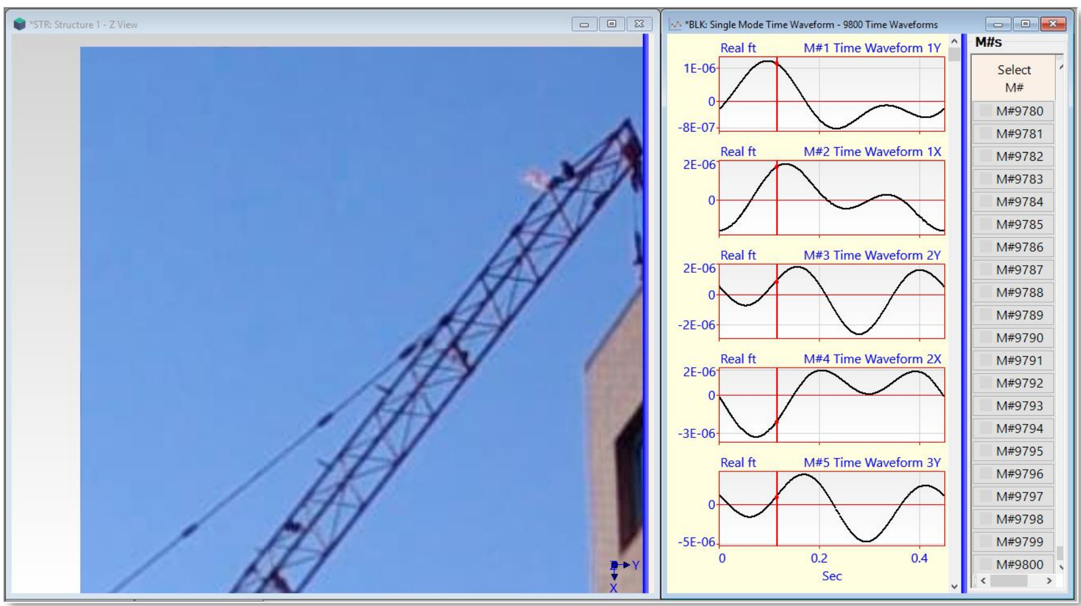

Figure 3. Time-Based ODS of a Crane Boom.

Frequency-Based ODS

- ***Two or more*** frequency domain functions calculated from ***phase-matched*** time waveforms constitute a **set of frequency-based ODS's**
- A **frequency-based ODS** is obtained at the ***same frequency sample*** in a set of frequency-based ODS's

A frequency-based ODS is obtained by placing a line cursor at the ***same frequency sample*** in a set of frequency-based ODS's.

A frequency-based ODS is shown in Figure 4. The ODS animation is created by modulating the ODS with sine wave values. Placing the line cursor at each one of the peaks in the spectrum shown in Figure 4 displays a different frequency-based ODS of the engine. The set of frequency-based ODS's used to create the animation contains ***10098 frequency spectra***.

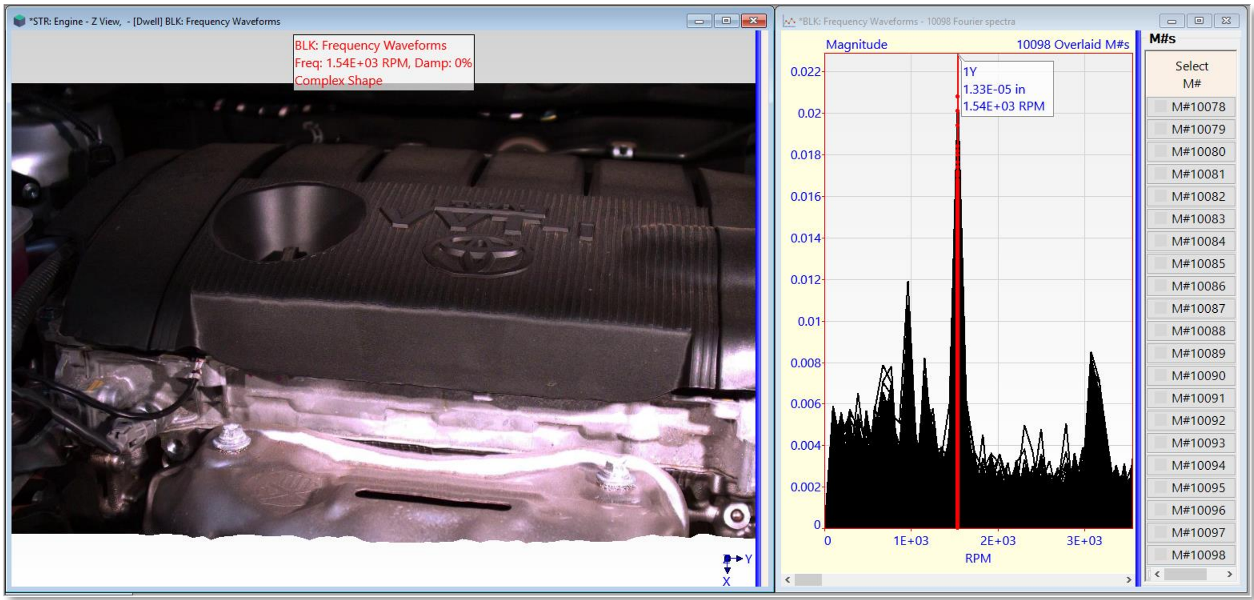

Figure 4. Frequency-Based ODS From a Camera with a Global Shutter

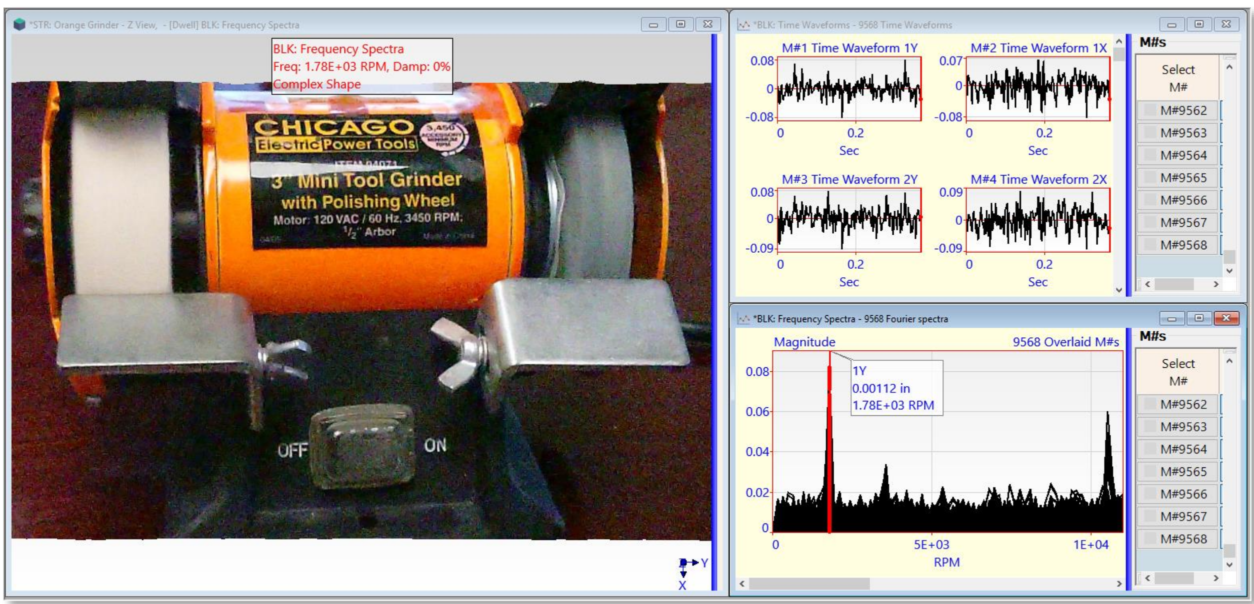

Figure 5. Frequency-Based ODS from a Cell Phone Video

3D Vibration

Different frequency domain functions; Linear spectrum (FFT), Cross spectrum (XPS), Frequency Response Function (FRF) Transmissibility (TRN), & ODS FRF [4], [7], can be calculated from ***two or more*** time waveforms.

- A Linear spectrum (FFT) is a ***single channel function***. The FFT is used to calculate a Linear spectrum from each time waveform
- All the other frequency domain functions are ***cross-channel functions***. They are calculated from ***at least two*** time waveforms

If ***two or more vibration videos*** are recorded from different viewing angles of a machine or structure, they can provide ODS's with ***3D deflection*** in them. If two or more cameras are used and their shutters are not synchronized, their time waveforms will ***not be phase-matched***.

But if a ***reference time waveform*** for the ***same point*** on the structure is extracted from each video, the reference time waveforms can be used to provide the ***correct relative phase*** for all cross-channel functions calculated from the video of each camera.

- ***Two or more*** frequency domain functions calculated from multiple videos, each with the ***same reference time waveform***, can be merged to constitute a **set of frequency-based ODS's**

RECORDING AN ODS VIDEO

After a set of time-based ODS's has been acquired from a vibration video and an ODS animation has been created using MEscope™ [6], a variety of unique features in MEscope™ can be employed before making a video recording of the ODS animation.

To create the ODS animation, a frame of the video is ***"attached"*** to a rectangular surface, as shown in Figure 6. This capability was pioneered by Vibrant Technology as a way of animating shape data on a 3D model with photographs attached to its surfaces. This is called a Photo Realistic Model. Examples of deformed Photo Realistic Models are shown in reference [5].

When the points on an underlying surface with a photograph attached to it are deformed during animation, the photo is ***"stretched"*** between neighboring points on the surface.

Figure 6. Video Graphics Attached to a Rectangular Surface.

This approach for creating an ODS video has significant advantages over other methods which merely ***"move the pixels"*** in the original vibration video,

- Animation of a time-based ODS at any time sample in a set of time-based ODS's
- Animation of a frequency-based ODS at any frequency sample in a set of frequency-based ODS's
- Control over the animation speed & amplitude
- Use of the original video color graphics
- Color contours superimposed on the video to indicate levels of vibration

- Display of the ODS magnitude & phase in displacement, velocity or acceleration units at key points on the structure
- Removal of camera jitter and background noise

Animation Speed & Amplitude

Either a time-based ODS or a frequency-based ODS can be used to deform a rectangular surface with the video graphics attached to it. The graphics is ***"stretched"*** to follow the grid points on the rectangular surface, thus providing an animation of the graphics from which an ODS video can be recorded.

Figure 3 depicts a time-based ODS of the crane boom displayed in animation by sweeping a cursor through the set of time-based ODS's. The sweep speed is controlled by either skipping over time samples or interpolating between them.

Figure 4 depicts a frequency-based ODS of an automobile engine displayed in animation at the cursor position in a set of frequency-based ODS's. Animation is created by modulating the ODS with sine wave values. Using four sine wave values (at 0, 90, 180, 270 degrees) creates the fastest animation. Using many sine values at angles between 0 & 360 degrees creates slower animation.

The amplitude of animation is increased by multiplying each ODS component by a larger number. The amplitude can be made as high as desired so that the deflection of the structure is clearly visible.

ODS Magnitude & Phase

The magnitude & phase of the deflection of selected points on a structure can be displayed with the animation and recorded as part of an ODS video, as shown in Figure 7. The large wobble of the left-hand wheel verses the right-hand wheel is very clear in the ODS animation and is also made clear by the magnitude & phase flags.

The time waveforms derived from a vibration video are in displacement units, as shown in Figure 7. Therefore, a time-based or frequency-based ODS will also have displacement units.

Velocity Units

In machinery maintenance applications, vibration levels in velocity units are commonly used to make maintenance decisions on rotating equipment. An ODS in displacement units can be differentiated to velocity units, hence the magnitude & phase of components at key points on the structure can be displayed in velocity units and in a video recording of the animation.

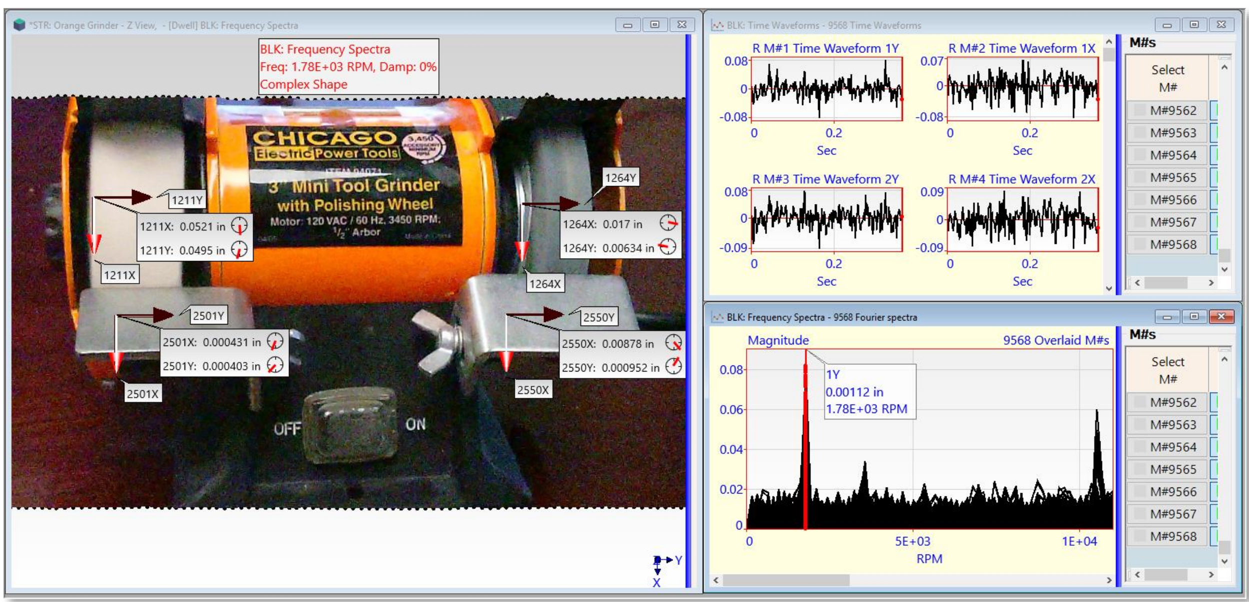

Figure 7. Magnitude & Phase at Key Points on the Structure.

Removal of Camera Jitter and Background Noise

Camera jitter typically occurs at lower frequencies than the vibration frequencies of interest on a machine or structure. These lower frequencies are easily removed from a set of frequency domain functions derived from a set of time-based ODS's. Once certain frequencies have been removed from a set of frequency domain functions, they can be Inverse FFT'd to provide time-based ODS's with those frequencies also removed.

Background noise can also be removed from a set of frequency domain functions by applying smoothing filters to them.

CONCLUSIONS

The fastest and most convenient way to capture the motion of a vibrating machine or structure is with a video recording. All other vibration measurement methods are more expensive and time consuming. In some situations, a video recording may be the only convenient way to measure the vibration. In most cases though, the level of vibration captured in a video must be increased in order to clearly see the deflection of the machine or structure.

We have used an Optical Flow method for extracting time waveforms from a vibration video recording. Then MEscope™ [6] was used to post-process the time waveforms and record a new ODS video with a clearly visible animated ODS in it.

ME'scope™ has a variety of post-processing features that can be used to interactively create an animated ODS display. After the speed, amplitude and other parameters have been selected for the animation, a new realistic video can be recorded from the animated ODS display. Unique features such as the magnitude & phase of the deflection at selected points and color contours that show levels of vibration can be added to the animation to enhance the information in an ODS video.

By using the graphics from the original video in the new ODS video, structural faults such as a loose or cracked foundation are easily seen by increasing the ODS amplitude during animation. With this new approach, vibration problems can now be visualized and documented in new and powerful ways using ODS videos.

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