Condition Monitoring by Using a Highly Directional Audio Detection System

Company presentation

Squarehead Technology AS was founded in 2004 and is located in Oslo Norway. The company consists of around 35 employees, with an established network of partners and customers worldwide, and is recognized as one of the world leaders in directional microphone technology.

Squarehead is all about directional audio, and are experts in audio and microphone technology. We are developing and manufacturing microphone arrays with several hundreds of microphone elements, and can combine several microphone arrays to build large scale systems.

Acoustic arrays

Seen in Figure 1 is an example of an acoustic array. The arrays can differ in both size and shape, but often consist of several hundred acoustic microphones, and an optical video camera. By using microphone arrays to record the acoustic signals as opposed to a single microphone, it is possible to single out a specific listening direction, or several listening directions simultaneously while attenuating surrounding noise. This in turn makes it possible to listen to several specific parts of a machinery with one microphone array, which can be placed at an appropriate distance from the machinery in question. By combining directional audio and video, we are able to visualize and localise selected audio sources.

Using acoustics for condition monitoring

Most organizations have at least one skilled maintenance person who can step onto the factory floor and sense—through sight, sound, smell, vibration, and temperature—the conditions in the factory. This person can tell in an instant that “The feeder on number 2 is hanging up a little this morning, so we’d better look at it.” The human senses of an experienced person are the best detection systems available today.

If a human can hear that something is wrong because the sound has changed from its normal state, then Squarehead's technology can provide super hearing, both on site or by remote access, to pin point where that noise is originating. Such super hearing may be especially useful in noisy and complex sound environments, where different noise sources greatly impair the ability to distinguish which machinery is producing a faulty noise.

With acoustic condition monitoring a machine running in a healthy condition has a known and stable noise spectrum. If this spectrum deviates from one or several predefined healthy states, this may be an indication of potential errors in the machine. Acoustic emission monitoring is also a non-invasive technology, and can be used while the equipment is operating and give instantaneous diagnosis and feedback. Such a system may provide information in three ways

- **Qualitative** with the ability to hear
- **Quantitative** via intensity (dB) readings
- **Analytical** with the use of spectral analysis

With our innovative software we are able to provide both live video and directional listening to specific parts of the machine under inspection online and in real time. This in turn gives the user access to both qualitative and quantitative information.

An example of an existing architecture is seen in Figure 2, where the user can connect to the system by a web client. This means that all software is run on a server at the test site. All calculations are run on the server side, and the client side is only used for access. This also means that the system is accessible by any platform such as Apple Mac or Windows computer, cellphone, tablet and so on.
Distributed arrays for remote listening

Seen in Figure 2 is the standard setup for multiple arrays connected to a single server. It is possible to run the system with a single array connected, or multiple arrays at the same time. The user can access the system by a web client. Since all processing is done on the signal processing unit on the array server, the client side does very little other than presenting results. This also means that multiple users can access the system at the same time. By using a VPN connection between the client and the server, the system is also protected against unauthorized access.

The system can either be used with a single array, or up to four arrays connected to the same server. By distributing several arrays it is then possible to cover different machines or interesting hot-spots simultaneously. Additional arrays and servers can be added for scalability if needed.

Squarehead’s microphone array systems have several advantages:

- One or more very directional microphone arrays can be installed to cover large areas
- Several arrays can be connected in a network for distributed coverage
- The system can use a sound-energy overlay video image to illustrate where the anomalies have occurred

Figure 3 shows the default web GUI of the system accessed by a web client. Here four microphone arrays are run simultaneously with live video and audio. The user chooses one of the array panes, and can then get directional audio from that array. The blue circle within each imaging pane is the virtual microphone. With the virtual microphone the user can get audio from a single point in the video image, thus listening to different parts of the machinery under inspection.
Advanced audio analysis software

In addition to remote control of several arrays with directive listening, it is also possible to record measurements and store them on the server on site. These measurements record all data from all microphones and can be transferred and downloaded locally for further advanced analysis. Since all information is saved, it is possible to perform all analysis of a recording in post processing, such as directive listening, graphical overlay of sources, spectrogram, FFT analysis and so on.

The standard analysis software is shown in Figure 6 where a tonal noise on a compressor is pinpointed by the graphical overlay.

Figure 4: Graphical overlay illustrating various audio events

Figure 5: Spectrogram analysis

Figure 6: Default software for advanced measurement analysis
Automatically disabling directive listening for privacy

Combining video and directive listening, both live and recorded, poses some concerns when it comes to privacy. What if there are people on site in the equipment’s field of view? Should they be afraid that someone could listen to their conversation?

Squarehead has always had a strong focus on privacy, and are actively working on solutions and features that avoid that the equipment can be abused. Both advanced video processing and acoustic voice activity detection are employed in the Squarehead products to disable directive listening for these type of situations, thus removing the concerns over privacy. As long as the system detects the presence of people or voice, all directive listening will be disabled.

Array specifications

**Audio and video**
- **Microphones**: 128 MEMS microphones
- **SNR per microphone**: 61 dB
- **SNR array (system)**: 82 dB
- **Audio sampling rate**: 44.1 kHz
- **Camera resolution**: 2592 x 1944
- **Opening angle**: 65°
- **Frame rate**: 15 FPS

**Frequency response**
- **Per microphone (flat)**: 100 Hz - 20 kHz
- **Array (spatial) sensitivity**: 410 Hz - 20 kHz
- **Per microphone**: -26 +/-3dBFS/Pa @1 kHz 94 dB

**Physical**
- **Dimension**: 41 cm x 48 cm, Ø 48 cm
- **Weight**: < 1 kg
- **Material**: Aluminium

**Power**
- **Power consumption**: < 2 W

![Figure 7: Motion detection view](image1)

![Figure 8: Person detection view](image2)

![Figure 9: Array spatial sensitivity plot (beampattern)](image3)