The colour of sound

*How acoustic cameras help us see the invisible. By **Richard Warrilow.***

"Where's that noise coming from?" It's a question we've often asked and one which would be easier to answer if we could 'see' sound. Our eyes can't, so our brains are left to process the sounds and then triangulate an approximate location. And if something is hard to hear, we tilt our heads a little – instinctively repositioning our ears to get better reception.

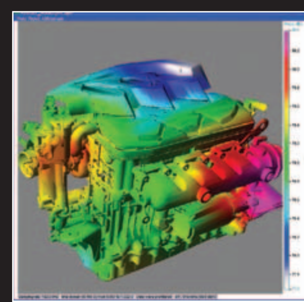
Because our ears seldom have identical performance, we are often deceived over the exact location of a sound, particularly if it is intermittent. Sometimes, the source of the sound may elude us completely. In some cases, locating and eliminating noise is of great importance. For instance, the luxury car industry pays particular attention to what it dubs BSR (buzz, squeak and rattle) issues.

Elsewhere in the automotive sector, noise – the right noise, that is – is desired and the characteristic deep throb on tick over of a performance car has always been a strong selling point. So there is great interest in seeing how sounds emanate from a car when designing its exhaust system and when fine tuning the engine.

Sounds can also play a role in automotive diagnostics and experienced technicians with 'an ear for the job' were diagnosing mechanical faults long before code readers came on the scene.

In other sectors, being able to see noise pollution would be of great benefit. With increasing road, rail and air traffic, faster production lines in factories and wind farms sprouting up, there is growing concern over the levels of noise affecting everyday life. Indeed, studies show that prolonged exposure to noise increases the risk of heart attack – and at night, disturbed sleep can affect our general health.

But where is all this noise? Until recently, recording and analysing the plethora of noises bombarding us would have been a time consuming and costly exercise; when all we really want to do is visualise how, and understand why, sounds are emanating from certain sources so that we might eliminate or at least reduce them.



There it is

Seeing the invisible is nothing new – xray machines, MRIs and infrared and thermal cameras have been doing it for years. Where sound is concerned, the use of static or directional microphones, amplifiers and an oscilloscope and/or spectrum analyser allows us to at least visualise the properties of sound.

The technology for visualising sound goes back several years and early pioneers included NASA, Boeing, DLR and Airbus. During the mid 1990s, these organisations, working independently, were creating colour acoustic images; using microphone arrays and conditioning hardware and software to produce 'sound maps'.

Also developing acoustic imaging technology

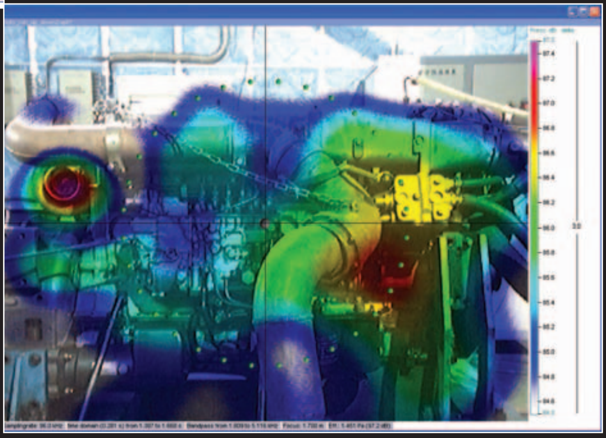
Right: *The noise generated by the turbine and rotor of a helicopter in flight.*

during the 1990s was GFaI eV, a research association which evolved from a department of East Germany's Academy of Sciences, which itself was almost completely disbanded with the reunification of Germany in 1989. Like MIRA in the UK, GFaI receives some government funding, but its main remit was and remains to commercialise its technological developments into products.

The real breakthrough in acoustic imaging came during the late 1990s when engineers at GFaI proposed using a video camera in the centre of an array of microphones to capture visuals, creating an automatic overlay to the acoustic image at the same time. And so the 'acoustic camera' was born.

Overlaying sound on top of real images – initially stills, more recently movies – continues to have great appeal. The start of the technology's commercial success was probably marked by Porsche's purchase of a system in 2001. Gunnar Heilmann, market development manager of GFaI tech, a subsidiary of GFaI eV located in the science and technology park in Berlin Adlershof WISTA, comments: "At the heart of the technology is a technique called delay and sum beam forming which, like the human brain, processes delays in the arrival of sound at different points."

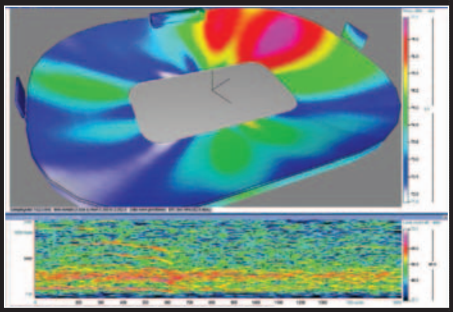
Tony Shepperson, sales and application engineer



of AcSoft, GFaI tech's UK distributor, adds: "You're effectively seeing noise in its fundamental form – changes in sound pressure – and in most cases you're acoustically focussing on what is optically invisible."

To capture a sound, practical beam forming requires a minimum of 16 microphones, but the more that are used the better the resolution and the dynamic range of the sound map. In some instances, more than 100 microphones are employed.

The microphones can be arranged in virtually any configuration, depending on application, but the most common for general applications are ring and spiral shapes. For measuring the noise of a passing vehicle, a three pronged star array might be employed. And for making all round 3d measurements (say within a vehicle) the microphones would typically be arranged in a sphere.



With this technology, it is possible to visualise sound in the range 100Hz to about 100kHz, where the low end is typically restricted by the array's dimensions. Lower frequencies require larger arrays with widely spaced microphones, while the upper limit is typically governed by the sensitivity of the microphones and the sampling rate of the data recorder.

Game On

Beam forming adds another dimension to standard acoustic recordings as the analysis of noise can now be time, frequency or space selective, which presents some interesting possibilities. Shepperson notes: "You might choose a plane in space and take an acoustic photo to see dominant sources for all frequencies. You could then record over a period of time – plotting frequency (y-axis) against time (x-axis) and using colour to denote amplitude – for an area of interest in your 'photo'."

It is possible to make a motion movie from sequential acoustic photos and GFaI has managed to capture images at a rate of almost 200kHz to produce extreme slow motion. "For example," offers Shepperson, "automotive power train developers are using the system in their test chambers to observe in detail individual firing sequences – and you can see what happens when the turbo kicks in."

Elsewhere, the technology has been used to analyse sound on a massive scale. Last year, recordings were taken by GFaI tech at the University of Michigan's 'Big House' stadium as part of an exercise to see how the addition of raised spectator boxes might affect noise levels.

Heilmann was on the Acoustic Camera team. He recalls: "The stadium is large, but does not have high sides. On the day of the recording, there were about 110,000 people in the stadium and we took our measurements from the centre of the pitch. An unexpected discovery was that we were able to zoom in acoustically on one individual and hear him above the crowd."

Sound levels in the centre of the field reached approximately 85dB, but nearer the edge of the field (particularly near the student section), it reached 112dB. The data was then superimposed onto a cad model, which has since been modified in accordance with architectural plans for the proposed changes.

Above:
The University of Michigan's 'Big House' stadium. The acoustic (still) photo of the stadium shows who is making the most the noise and, below it, a frequency (y-axis) against time (x-axis) plot in which colour denotes amplitude. The plot represents a 1.5s recording of one section of the crowd.

Centre:
The automotive industry is interested in acoustic imaging to make sure engines produce the 'right' noise.

Right: *Acoustic cameras have a typical range of 100Hz to 100kHz, which makes it possible to 'see' ultrasonic sound. Visit* ***www.newelectronics.co.uk*** *to see a short movie clip of the sounds emitted in flight by Bartok the Egyptian Fruit Bat.*

Above and right: *Practical beam forming requires at least 16 microphones, but the more that are used the better the resolution and the dynamic range of the sound map.*

Heilmann says: "One reason for the addition of the spectator boxes is to reflect sound into the centre of the pitch, as part of the game from the spectators' point of view is to drown out the quarterback's instructions to his team. It's anticipated that the addition of the boxes will result in at least a 10dB rise in noise on the pitch during a typical game. We plan to return following the construction of the spectator boxes to make new recordings."

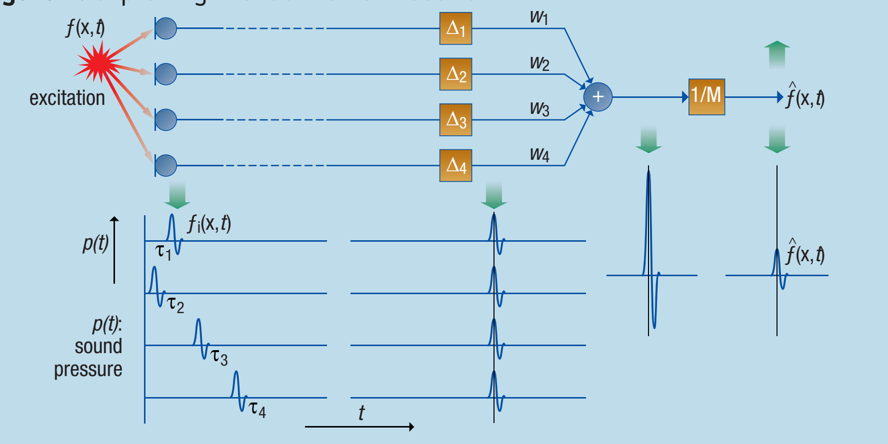
From A to Z

Using our eyes, we can gather information more quickly than through using any other sense and, according to Shepperson: "The main issue is not that humans can't hear noise, it's about developing an objective approach to reducing or eliminating it. For example, one automotive manufacturer came to us with 40 known noise sources inside the car, but it wanted to know how often they occurred under varying conditions so it could prioritise the remedies."

Whilst acoustic cameras are relatively new, they have already proved useful in applications ranging from aerospace to zoology anprocessing power has made possible real time 2d and 3d acoustic imaging.

Heilmann concludes: "Acoustic imaging will play an increasingly important role in quality control, environmental inspections and architectural analysis. Acoustic imaging has a very colourful future." ■

Figure 1: Capturing the location of a sound



In figure 1, left, the red star represents an excitation (say an audible click) which arrives at the four (blue) microphones at different times. The delays between arrival times is used to calculate the sound's position in space – which is represented by a pixel on a photograph produced by a camera also 'looking at' the source. The delays are normalised and the signals summed to produce a composite sound, which is assigned to its corresponding pixel.