ACOUSTIC IMAGING TECHNIQUES

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Abstract

This report provides an in-depth exploration of acoustic imaging, a versatile imaging method which utilizes sound waves instead of traditional optical cameras. The report begins by reviewing the origins of acoustic imaging, tracing its evolution from ancient practices to its current applications in various fields.

The report delves into the aspects of acoustic imaging, focusing on techniques such as scanning acoustic microscopy (SAM), sonar, medical ultrasound, and airborne ultrasound imaging. SAM's non-destructive imaging capabilities and superiority over optical microscopy and X-ray techniques, along with sonar's diverse variations and widespread applications in military, scientific, and consumer domains. Additionally, medical ultrasound's non-invasive nature, versatility, and various modes of operation, highlighting roles in prenatal care, diagnostics, and medical imaging.

Furthermore, the report explores emerging technologies in acoustic imaging, such as the integration of optical and acoustic technologies to pinpoint sound sources visually. It examines innovative devices like the Fluke ii900 series acoustic imaging cameras, which are revolutionizing production plant maintenance. The potential of microphone arrays and beamforming techniques in airborne ultrasound imaging, underscoring their role in enhancing inspection efficiency and automation.

Introduction

Acoustic Imaging describes a sort of imaging method that employs sound to form the image rather than a traditional optical camera. Acoustic Imaging devices rely heavily on a transducer to both send and receive sound waves. A transducer is a piezoelectric device that converts forms of energy from one domain to another. For most cases of acoustic imaging the transducer converts sound waves into electrical signals like a standard microphone. The transducer can also work in reverse to create sound waves from electrical signals. The transducer is for sending and receiving applications where a pulse is emitted, and the return of the reflected wave is used to measure some object.

The earliest forms for using sound to determine the state of objects go back millennia to Hippocrates in ancient Greece. Hippocrates was a doctor known to shake his patients by the shoulders to determine the amount fluid was present in their lungs. Later scholars like Leonardo DaVinci and even later Lord Rayleigh pioneered the science of the propagation of sound through water. These discoveries were the foundations of one of the most popular forms of acoustic imaging, Sound Navigation and Ranging, also known as sonar. Other techniques such as Scanning Acoustic Microscopy (SAM), medical ultrasound, and airborne ultrasound imaging are all widely used in their applicable fields for non-invasive ways to detect the integrity of objects at resolutions far superior to purely visual imaging techniques like X-Ray.

Current advancements of acoustic imaging are combining optical and acoustic to display live information that can pinpoint the source of a sound in a visual sense that aids the operator in finding the source of the sound. Devices such as the Fluke ii900 series acoustic imaging cameras are in the process of revolutionizing production plant maintenance with the ability to spot leaks and wearing bearings which often emit sounds imperceptible by the naked ear.

Technical Information

Scanning Acoustic Microscopy (SAM)

Scanning Acoustic Microscopy (SAM) is a non-destructive imaging technique used to visualize the internal structure and properties of materials. Alternatives purely optical such as microscopes can only see the top surface. X-Ray has similar uses as SAM for visualizing the internals as well but is far less accurate and has a far lower resolution.

It works by generating a high frequency ultrasound wave from a transducer. The higher the frequency, the thinner the material or object you wish to observe. These waves emit toward the object or material. When the ultrasonic wave hits the object, they change speed or amplitude to show edges or boundaries. These reflections will return to the transducer and provide accurate information about the object's internal structure. The system will process the signals into a grayscale image showing boundaries of the object and imperfections such as cracks, voids, and delamination effects as darker than the surrounding material.

Quality control in electronic, aerospace, biomedical, and manufacturing personnel to detect defects using SAM.

Sound Navigation and Ranging (SONAR)

Sound Navigation and Ranging (SONAR) is an exceedingly popular in military, scientific, and consumer uses to map or detect objects underneath the surface of the water. The first sonar systems developed ahead of the First World War with the first patent established in 1913. Active sonar works by sending out an audible blip and waiting for a reflection off an object like an enemy submarine. Passive sonar simply waits and listens to blips from other sources. Though sound travels through water much better than it does through air, sonar pulses still need to be extremely loud to traverse miles to the detected object and back. Sonar pulses can be as loud as 300 dB at the source, well beyond the safe range for human and aquatic lives.

A variation of sonar found on military vessels is Doppler Sonar. This can use the Doppler effect to determine the speed and direction of objects found by a typical sonar pulse. This works by analyzing the frequency shifts of the reflected pulses.

Another variation is Side Scan Sonar. Researchers use this to map the sea floor by emitting pulses in different directions to form a map or image of the sea floor. Researchers also use this for hydrographic surveying, and marine research. The common Fishfinder used by fishers to detect fish also uses this kind of sonar.

Medical Ultrasound

Medical ultrasound, also known as diagnostic medical sonography or ultrasonography, is a non-invasive imaging technique used to visualize internal organs, tissues, and structures within the body. It uses frequencies in the range of 2-18 MHz to propagate sound waves through the soft tissues within the subject. It is frequently used in prenatal care to monitor fetal development during pregnancy and detect abnormalities. A technician will apply ultrasonic gel to the area to help eliminate an air gap between the transducer and the patient which can disrupt the sound waves. The gel also reduces friction when sliding the handheld transducer across the body as well as having a cooling effect as the transducer can heat up over prolonged periods.

There are distinct types or modes associated with medical ultrasound. A-Mode, or Amplitude Mode, constitutes a one-dimensional ultrasonic measurement technique wherein the amplitude of individual pulses is measured by the transducer. B-Mode stands for brightness mode and is the most common mode for medical ultrasounds. B-Mode has an array of transducer elements and scan through a plane of the body or subject that results in a two-dimensional image output. M-Mode is an extension of A-Mode and takes A-Mode emissions successively to create an image that is like B-Mode. C-Mode is a series of B-Mode emissions to create a three-dimensional image.

Airborne Ultrasound Imaging

Airborne ultrasound imaging is a type of acoustic imaging mostly used for inspection of electrical or mechanical equipment. It usually requires a handheld microphone and an operator with headphones to hear previously imperceptible sounds. These sounds can include feint gas leaks from a valve or seal, a high-pitched ringing or whine from a ball bearing in need of maintenance. This is an old-fashioned method of inspection and is at the mercy of the operator pointing the probe in the general direction of the noise of which they cannot hear.

Advancements made in this field have been ditching the small probe in favor of a full array of microphones as well as a visual readout of the area. New to market devices like the Fluke ii900 series revolutionize the inspection capabilities of the operator by reducing the need to estimate the area of the sounds. This is to reduce the need for human inspectors as well. Boston Dynamics' Spot quadrupedal robot can equip these devices, patrol manufacturing plants and alert technicians when it finds a loud. This robot can stream the output to a trained inspector to verify and fix the source of the sound on demand with increased efficiency.

For microphone arrays, beamforming is useful for finding the loudest sound in an area. Beamforming calculates slightly delayed signals across the microphone array to triangulate the origin of the sound. In a known medium, the speed of sound is known, and the source emits a sound which takes a known amount of time to reach a microphone. This same sound will reach every microphone at slightly delayed intervals and with trigonometry can produce the direction and distance of the received sound.

Discussion

Areas which I found especially interesting were the three-dimensional acoustic cameras. These setups used omni-directional microphones arranged in three-dimensional space. This eliminates inaccuracies from two-dimensional arrays from the slight parallax between the microphones. Another area which piqued my interest was acoustic holography. This is a way to store a sound field, a three-dimensional snapshot of all the sounds in an area. It surprised me to find so many slight variations of all these different techniques meant for specific applications.

Conclusions

In conclusion, this report has provided a comprehensive examination of acoustic imaging techniques, highlighting their historical roots, technical aspects, current applications, and emerging trends. From ancient practices to modern innovations, acoustic imaging has evolved into a versatile method for visualizing internal structures and detecting defects in various materials and objects.

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