Acoustic Surveillance

3

Infra/Ultrasound

1. Introduction

The previous chapter on audio surveillance focuses on sounds within the range of human hearing. However, there are sounds outside of human hearing that can be heard by many creatures including moths, dolphins, bats, cats, and dogs. These sounds can also be generated by machines and used to communicate signals, measurements, or conversations that are useful in surveillance.

This chapter introduces *infrasound*, sounds at frequencies below human hearing, and *ultrasound*, sounds above human hearing. Sonar, which historically was within audible hearing ranges now primarily uses ultrasound. Since sonar is a specialized area widely used in surveillance, it is covered separately in Chapter 4. Since they are somewhat related to sound waves, devices that detect shock waves are also discussed here. Sound waves and shock waves are not the same, but devices to detect them are very similar. For an explanation of the distinctions between these phenomena, see Section 5 (Description and Functions).

Infra/ultrasounds have many advantages as surveillance tools. They can be used to signal or communicate without attracting attention. Depending on the application, they can be eco-

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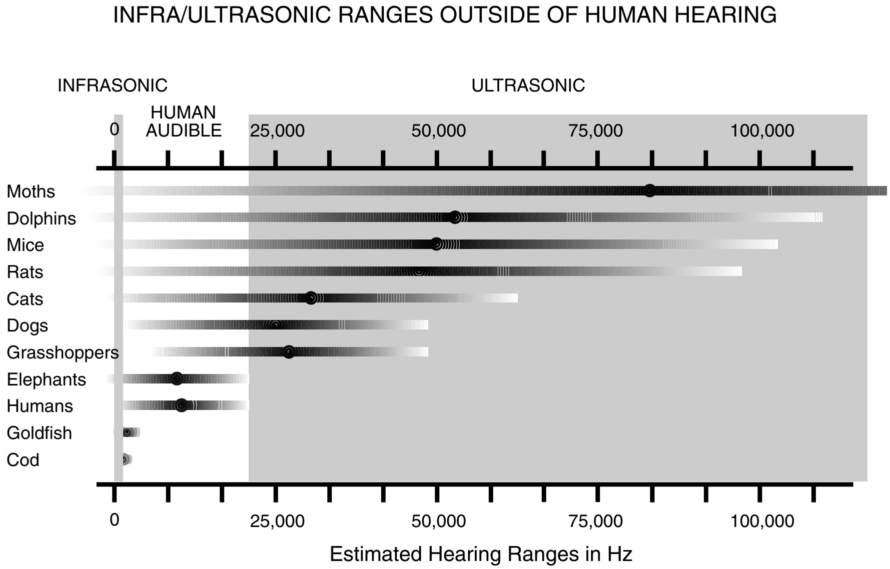
A severely damaged stretch of highway in Oakland, California, following the Loma Prieta earthquake. Infrasound detectors can aid in predicting many different types of natural disasters in order to warn residents to avoid roads or to take shelter underground. [U.S. Army Corps of Engineers news photo, public domain.]

nomical, as it is easier to generate certain sound frequencies and listening devices than it is to generate many types of electromagnetic transmitters/receivers. Sound is also less apt to be harmful in normal use than some forms of electromagnetic radiation. Sound waves are versatile. They can be used to detect objects, to measure distances, to map contours, and to create a 'picture' of objects within other objects or structures. Sound is used in applications as diverse as locating submarines, navigating through oceans or caves, sending messages, testing the structural integrity of buildings, assessing quality on a production line, and imaging a growing fetus inside a womb. The ability to look through particulate environments or 'inside' certain opaque materials is a very useful capability of sound.

Much of our knowledge of infrasound and ultrasound has come from studying the anatomy and behavior of animals, insects, and fish. In some cases, humans combine the abilities of various species of animals with other surveillance tools. Dolphins and dogs, which recognize and respond to signals above human hearing, have been trained to perform certain surveillance tasks. Humans have also made use of the sound-sensing abilities of other species as warning or searching aids.



Chapter 2 on audio surveillance and Chapter 4 on sonar surveillance provide most of the introductory and specialized information needed to understand acoustic technologies related to surveillance. This chapter is intended to introduce the general concepts related to inaudible acoustics below and above human hearing, called infrasound and ultrasound.

- As can be seen from the above chart, infrasound is a very small portion of the sound spectrum and yet it is highly important as a monitoring technology for predicting and studying larger events such as storms, earthquakes, floods, and nuclear explosions. Infrasound is also used in compact pressure-vibration-based motion detectors.
- Ultrasound covers a much larger spectrum of frequencies than infrasound, and it is widely used in navigation, depth-sounding, and medical applications. Most aspects of medical imaging are outside the scope of this text, but it is worth mentioning that ultrasound can be used in forensic investigations of homicide or accidental death. Ultrasound is also used for robotics control. The marine applications of ultrasound,

especially sonar, are many. The majority of sonar technologies now operate within ultrasound frequency ranges and are described in the following chapter.

1.a. Basic Concepts and Terminology

As illustrated by the shaded regions in the chart on the previous page, sounds with frequencies above human hearing are called *ultrasonic* and those below human hearing are called *infrasonic*. Human-audible sounds are called *sonic*.

Infrasonic vibrations are those with frequencies below 17.5 ± 2.5 Hz. Ultrasonic vibrations are those above 19,000 ± 1,000 Hz. Different texts and branches of science use different cutoff points, but most infra/ultrasonic designations are within these limits. In terms of biology, there are no definite cutoff points, since hearing varies from person to person and changes as we age. Political bodies sometimes specify cutoff points in order to establish policies, such as those for detection devices associated with international disarmament.

Infrasonic vibrations can sometimes be converted to audible sounds by recording the vibrations with sensitive microphones and then speeding up the replay. The same can be done, to a limited extent with ultrasonic vibrations near the upper level of human hearing. However, we usually use other instruments to record and display infra/ultrasonic sounds, often converting the data into a graphical representation.

The frequency is separate from the intensity or ‘loudness’ of a sound (e.g., a 50,000 Hz ultrasonic vibration can have a high intensity and still would not be heard by humans). Intensity is expressed in units called *decibels* which are described along with an illustration of sound waves in the following chapter.

Infrasound and Seismography

A *seismic* vibration is a disturbance or *shock wave* in a celestial body such as the Earth or the Moon. Events that cause shock waves generally create acoustic disturbances at the same time. Some people refer to a shock wave as an intense acoustic wave, although scientists prefer to make a distinction based on the character of the shock wave, which travels very fast through an elastic medium, creating a conical wavefront. Since there are similarities between acoustic waves and shock waves and the detectors that sense them, seismic waves are discussed along with acoustic waves in this chapter. Seismic and acoustic vibrations can yield important information about large-scale events such as floods, tidal waves, slides, earthquakes, the impact of an asteroid, and volcanic eruptions. We describe them as shaking or rumbling sensations, often with low-level sounds that are more felt than heard. Acoustic waves can also result from chemical or nuclear explosions.

A *seismograph* is an instrument designed to record and display seismic vibrations. Seismographs are important tools for earthquake prediction and disarmament-treaty monitoring. Early seismographs used pens to trace lines on paper. More recent seismographs may use computer monitors to display digitally processed information. Some even have warning capabilities that will email data to a predefined address or set off alarms that will wake a scientist or graduate student interested in observing cataclysmic events such as the impending eruption of a steaming volcano.

Elephants are able to sense infrasonic vibrations down to almost the lowest end of the scale. They even communicate with one another using infrasonic vibrations that can’t be heard by humans but may sometimes be felt as body vibrations. If you consider that elephants are large animals with broad feet that have a constant solid contact with the ground, it makes sense that they have evolved the ability to interpret some of the deeper vibrations that form part of their environment.

Ultrasound

The main applications for ultrasound are sonar, industrial materials testing, and medical imaging. Sonar is discussed in the next chapter. Medical imaging is a large and growing field beyond the scope of this text, but it's worth noting that most ultrasound systems are designed to convert acoustic information into a visual representation on a graph or computer monitor. This image can be a series of still frames or a realtime representation of movement, like an animation. The images can be inversed (like a negative), grayscale (to look more natural), or pseudo-colored (sometimes called false colored), to help to interpret the image. An ultrasound printout is called a *sonogram* or *sonograph*. Sonograms are sometimes printed on photographic film to resemble X-ray images.

The term *sonic* is sometimes incorrectly used to represent 'ultrasonic' (perhaps this came about for reasons of brevity). The term sonic correctly refers to sounds within the audible human hearing range.

1.b. Other Sound Concepts

The Sound 'Barrier'

When objects, bats, or birds fly, they create pressure waves in the air, but the disturbance is so minimal, it is hardly noticed. However, when objects travel very, very fast, they build up a region of pressure at the forefront of the nose or wings that becomes more and more difficult to overcome. Engineers thought the speed of sound might be the upper speed at which airplanes could fly, so they labeled it the *sound barrier*.

A dramatic moment was captured by photographer John Gay as an F/A-18 "Hornet" broke the sound barrier in July 1999. The light region represents the area where a massive pressure wave built up on the front of the jet, as it flew progressively faster. Then condensation formed as the air cooled to create a visible cloud as the jet broke through. When aircraft like military jets or the Concorde commercial jetliner break through the sound barrier, they create a *sonic boom* that can be heard for great distances. The industry is regulated so that the sound barrier is only broken away from populated areas. [U.S. DoD news photo, released.]

With the right design and sufficient energy, however, it is possible to break the sound barrier. This happens, for example, when a bullet is fired from a gun. When a large object, like a Concorde jet, successfully breaks through the sound barrier, there is a dramatic pressure disturbance called a *sonic boom*, which is a high-intensity burst of sound that covers many frequencies, resulting from the *shock wave*. Sonic booms are so loud and disturbing, in fact, that the commercial use of fast jets is strictly regulated. They are only permitted to cross the sound barrier at certain times and locations (e.g., over the ocean). Sonic booms also limit the ways in which very-high-speed surveillance jets are utilized to carry out reconnaissance missions. They are flown on schedules and from locations that minimize the chance that the boom will betray their presence.

Sound Zones

The phrase *dead zone* is often used in connection with sound applications. Since sound is dependent upon the medium through which it travels, changes or variations in the medium will affect the pitch and speed of the sound and even the direction of travel. Some objects will 'block' sound, causing the sound waves to pass over or around the obstruction. In general terms, a dead zone is an unresolvable area, a region in which there is no sound, and so the sound probe cannot provide any useful information.

It is important to understand dead zones in terms of imaging and testing, so as not to confuse the dead region in the data or image as an actual object. For example, when you use sidescanning sonar on a boat, there will be a dead zone in the center between the right and left scans in which no data is being acquired. It should be interpreted as an unresolvable area rather than as a physical trench below the boat. That might seem obvious, but sometimes the effect is not so obvious. When the sidescanning sonar sweeps outward from the boat, the objects on the right and left will protrude to different degrees and cast sonar 'shadows' on the side of the objects that are away from the boat. It will appear as if nothing is there, when in fact there may be many protrusions within those unresolvable areas that aren't showing up on the scan because the sound never reaches them.

In industrial testing with ultrasound, there may be a dead zone between the resolving area of the probe and the material next to the area of the probe wherein the pulse cannot be processed, in other words, a region that is too close for the pulse to 'focus' to provide useful information. There may also be dead zones created by materials that cannot be penetrated by the sound.

Frequencies Used for Surveillance

To make a sound wave inaudible to humans, we generally manipulate its *intensity* and/or its *frequency*.

- Intensity is perceived by us as the loudness or softness of a sound. Intensity-control has some obvious applications in surveillance. A whisper is less likely to be heard by prying ears than normal speech and a tiny earphone held next to the ear is less likely to be noticed than a loudspeaker on a handheld radio or speakerphone.
- As has been mentioned, frequencies below 15 Hz or above 20,000 Hz are inaudible to humans. Our ears and brains aren't equipped to sense below and above those thresholds which means that these frequencies can be used to covertly convey information or to take measurements.

This chapter concentrates on technologies that use frequency to provide covert communications or which are designed to detect phenomena that we can't hear with our unaided ears.

More of the basic concepts and attributes of sound are described in the introduction sections of Chapters 2 and 4, and you may wish to scan those sections before continuing here.

2. Types and Variations

A number of technologies have been developed to detect non-audible sound waves. Infrasonic detectors can be land or water based.

- *Hydrophonic detectors* are commonly used to detect acoustic waves underwater and *seismographs* are commonly used to detect ground-level shock waves. Most hydrophones are general purpose; they detect sounds within a wide range of frequencies.
- Most seismographs are specialized to detect low-frequency pressure waves (so that they don't react to every honking horn or spoken word). Depending on their design, sensitivity, and location they may respond to slamming doors, moving feet, traffic rumbles, earthquakes, and strong tidal currents.
- *Vibrational motion-sensors* are somewhat like specialized seismic detectors. These small, infrasonic surveillance devices can be placed near entrances or restricted areas to detect approaching footsteps from people or animals and can sound an alarm or activate other surveillance devices.

Ultrasonic sonars are usually used in marine environments, though some are used for controlling robots on land. Ultrasonic detectors for medical and industrial purposes are usually used on land, but typically in conjunction with liquids or gels to aid in sound conduction between the detector and the material being checked.

3. Context

All surveillance technologies have to deal with clutter*, unwanted information of one sort or another, and infra/ultrasonic applications are no exception. Infra/ultrasound technologies are used in many different sciences and the means for interpreting the signals will depend in part on what type of information is desired and how accurate it needs to be.*

Since infrasound is used largely to monitor large natural events and explosions, there is a need to determine the source of the disturbance, the speed at which it is moving or dissipating, its magnitude and location, and its potential for harm. National weather and disaster-relief organizations are continually dealing with these issues and seeking to improve their surveillance technologies and forecasting abilities. The results are not always perfect, but there have been many strides in the last decade, particularly with satellite sensing, Doppler radar, and more sophisticated computer processing and display technologies providing additional data. With these tools it is becoming somewhat easier to predict major earthquakes, the path of a storm, avalanche activity, rock slides, and lava flow from a volcano. Devices are also used to monitor global political conflicts and compliance with disarmament treaties.

Seismographs can be used to detect infrasonic disturbances and shock waves, but distinguishing a natural event from a human event, such as a nuclear explosion, is both art and science. Identification patterns and criteria have been established to aid in the making of a 'best guess.' The *mb/Ms* method is one means of comparing the magnitude of *seismic body waves* to *seismic surface waves*. Thus, among other things, the influence from events above ground can be compared with events below ground to yield a profile of the event. In other words, a volcanic eruption may have different characteristics and a different mb/Ms profile than an earthquake or a tidal wave. When this information is compared with decades of collected data for various types of events it provides a guideline for analysis within certain confidence levels. Local data on the surrounding geology can be combined with generalized data to narrow the evaluation even further. Data from other sensors can help round out the picture. Satellite photos, radiation detectors, broadband hydroacoustic detectors, and X-ray images can all be used in combination with seismographic detectors.

While no exact numbers are known, it is estimated that there are over 10,000 seismic monitoring stations worldwide, and the International Monitoring System (IRS) has almost 200 seismic stations. Many of these stations have a variety of detectors and can monitor shock waves and infrasound waves at the same time. There is considerable collaboration between different monitoring stations; data from several stations can be cross-referenced to reveal a better picture of the source and velocity of a disturbance. The data can also be used to cross-check individual stations to make sure equipment is working correctly and to eliminate data from faulty stations that might otherwise skew the overall results.

Simultaneous seismic events can sometimes be difficult to distinguish from one another or may make identification more difficult if one is deliberately used to mask others. For example, a nation testing nuclear explosions could detonate more than one device simultaneously, obscuring the exact nature of the activity and making it difficult to determine the magnitude of the event or whether there was one or more explosions. *Low yield tests*, those which are of lower magnitude, or tests conducted within insulating geographic structures can also be difficult to detect.

Industrial Testing and Safety

Ultrasound is an important aspect of flaw detection and quality assurance in industrial manufacturing. Computerized ultrasonic detectors are now routinely used to inspect welds, joints, cracks, laminates, and many other materials and fabrications. Ultrasonic detectors are usually *resonance systems* or *pulsed system*s. The basic ways in which ultrasound testing is conducted include

- *immersion testing* - materials are put in a liquid bath with fluids that are suitable for the type of material used and the testing probe is immersed as well, to send sound vibrations through the liquid medium and materials (sound doesn't travel well between air and liquid, as it will refract, hence the liquid medium), and
- *contact testing* - materials are coated with a liquid or gel to provide a good contact between the ultrasonic probe and the materials being tested. This method is not suitable for all types of materials, but is convenient and makes it possible to develop portable detectors.

Surveillance of infra/ultrasound is important in industrial work environments because workers cannot directly hear sounds outside of human hearing ranges which may, in fact, be intense enough or persistent enough to cause damage to hearing. For worker protection, various health and hearing agencies have established commercial and industrial guidelines for noise levels, ear protection, and worker exposure.

The U.S. Army Corps of Engineers, for example, has established guidelines for safety and health. The National Institute for Occupational Safety and Health (NIOSH) *Hazard Evaluation and Technical Assistance* (HETA) program responds to requests to examine hazards in the workplace, including acoustical hazards. HETA uses infrasound measurements along with audiometric testing and noise evaluation to assess an environment. (Other general health organizations that publish acoustic standards and guidelines are listed in the Chemical Surveillance chapter *Resources* section.)

4. Origins and Evolution

Note, ultrasound shares a common history with sonar technologies. It is recommended that you cross-reference the historical information in the following chapter with the information provided here.

Infrasonic and ultrasonic devices do not have a long history, as compared to optics, for example. They did not really become practical until there was a greater understanding of electronics and of methods of sending and detecting controlled acoustic resonances or pulses.

Infrasonics and Early Seismologic Studies

Records of cataclysmic events go back thousands of years and the ancient Greeks may have had some early earthquake-recoding technology that was sensitive to shock waves and infrasonic vibrations.

Chang Hêng, a Chinese philosopher, is reported to have invented the earliest known seismoscope, in 132 A.D. The instrument was a ceramic urn, adorned with eight open-mouthed dragons about its middle, each mouth sporting a small ball. If the urn was disturbed by a ground vibration, it would tilt and discharge one or more balls in the mouths of waiting ceramic frogs at the base of the urn, thus indicating the magnitude of the disturbance and its direction of origin [Needham, 1959]. News of this innovation does not appear to have reached the western world at the time, or if it did, the records were lost.

In 1783, an Italian clock-maker, D. D. Salsano reports his invention of a ‘geo-sismometro,’ a geoseismograph based on a brush suspended on a pendulum, that could make marks with ink on an ivory slab, a concept not far from later seismographs.

Robert Mallet, an Irish engineer responsible for the design of many London bridges, made some initial studies of seismic waves. Mallet had a novel approach. In 1851, he used gunpowder to create explosions and then studied the different geological effects of the pressure waves through the Earth, particularly the velocity of the waves.

Other European scientists up and down the western coast of Europe were making similar studies, perhaps motivated by a series of strong earthquakes that had taken place in the previous century. Some came up with interesting ideas for recording earthquakes, including the use of mercury- or water-filled vessels.

The ruins of City Hall (left) and rubble-clearing (middle) after the 1906 San Francisco earthquake. Mass destruction from the quake prompted the improvement of earthquake-prediction technologies and more stringent building codes. The after-effects of a quake (right), such as floods and fires, can also have devastating consequences. [Library of Congress photos from the Detroit Publishing Co. and Pillsbury Photo Co., copyright expired by date.]

By the mid-1800s, detection instruments were becoming more sophisticated, able to measure a number of different attributes of a phenomenon. As clock-making improved so did scientific instruments, which had many components in common with precision clocks. In

1856, a ‘sismografo elettro-magnetico,’ an electromagnetic seismograph, was installed by Luigi Palmeire in a volcanic observatory on Mount Vesuvius. It was intended to provide a variety of measurements, including direction, duration, and intensity. This device is also significant for the fact that it was intended to measure both horizontal and vertical movement.

The Lassen Volcanic National Park was established in 1916 in response to eruptions of Lassen Peak around 1914 that continued to 1921. Sometime after 1916, the Loomis Seismograph Station was constructed in the park to sense shock waves and provide readings. [Library of Congress HABS/HAER collection 1976 photos by Fred English, public domain.]

In the late 1800s and early 1900s, there was also a lot of interest in the study of earthquakes in Japan and both western and Japanese researchers based in Japan contributed to the emerging science of seismology. Some important quantitative scientific discoveries were made by Sikei Sekiya in the process of studying earthquakes and John Milne was instrumental in the founding of the Seismological Society of Japan in 1880. Milne later spearheaded the establishment of global seismic monitoring stations.

Ultrasonics - Early ‘Reflectoscopes’

The *reflectoscope* was one of the earliest ultrasonic devices, but the term sometimes causes confusion because there were even earlier devices called ‘reflectoscopes’ that had nothing to do with sound; they were visual projection devices used to enhance lectures in the early 1900s. Visual reflectoscopes were often used in conjunction with other projection devices called *stereopticons*. Oldtimers may remember them as ‘magic lanterns.’ These evolved into present-day *opaque projectors* and the stereopticons are today’s *slide projectors*. The Boston City Council authorized that schools be provided with electric ‘stereopticons’ and ‘reflectoscopes’ in 1902. Tuck Hall, the first business school in America, had its lecture room equipped with a stereopticon and reflectoscope at least as early as 1904. Thus, the term was in regular use before sonar and other modern acoustic-sensing devices were even invented.

As visual display devices evolved, they took on names more specific to their functions and the term reflectoscope was borrowed by inventors to describe acoustic sensing devices. The term is appropriate, since it is descriptive of the way sound is projected out from the projecting device, similar to the way light is projected out from a magic lantern. Just as the light is ‘read’ when it hits another object and reflects the image back to our eyes, most sound-detection instruments read reflected energy when it returns to its source or a receiving device at some other location.

Some of the earliest, most rudimentary acoustic ‘reflectoscopes’ began to emerge in the late 1930s but they didn’t have the imaging capabilities of later systems. Up to this time, most sound technologies were within human hearing ranges because the technological means to generate high-frequency sounds weren't yet practical. Electronics needed to become more fully developed. (The emerging concepts of ultrasound were gradually applied to sonar, as well, as described in Chapter 4.)

Rail Expansion and Quality Control

As with so many other technologies, testing techniques for expanding rail systems arose, in part, because of a tragic accident. In 1911, in Manchester, New York, a train derailed, killing almost three dozen people and injuring dozens more. The U.S. Bureau of Safety investigated the tragedy and concluded that a rail with a defect that was not visually apparent was probably responsible for the event. When other tracks were subsequently inspected, it was found that the Manchester rail defect was widespread.

Heightened awareness provided an opportunity for inventors to create detection/inspection devices that could potentially save dozens if not hundreds of lives and prevent the damage of costly rail cars. A number of experimental techniques for rail inspection were tested, including sound probes and magnetic probes.

One of the inventors interested in tackling this challenge was Elmer Ambrose Sperry (1860-1930), who is best known for his invention of the gyroscope, an instrument now incorporated into gyrocompasses, which are an important tool of navigation. In 1923, Sperry initiated the development of a rail car especially designed to inspect lengths of track and to look for the type of transverse defect that had been discovered in the broken rail in Manchester.

Top and Bottom Left: A cleanup crew surveys a train wreckage on the Intercontinental Railroad (ICRR) in Illinois, in October 1909. Bottom Right: A train wreck in 1914 illustrates the need for technologies to detect defective tracks and to maintain tracks once they are laid. The same technology can be adapted to check the structural integrity of the bridges and trains as well. [Library of Congress photos from International Stereograph Company, and photo from the South Texas Border collection by Robert Runyon, public domain by date.]

Sperry's initial experiments involved the use of magnetic flux to seek out defects in the rails. These magnetic detectors were used for a time. Later experiments in the use of ultrasonic detectors showed significant promise, gradually overshadowing the magnetic detectors. (See the Magnetic Surveillance chapter for more information on Sperry's early detection devices.)

Display Technologies and Ultrasonics

The invention of the cathode-ray tube became a great boon to many detection technologies. Oscilloscopes, radar and sonar scopes, and scopes that could be used with future ultrasound devices began to be mass-produced around the mid-1930s, providing a means for visually representing sound and electromagnetic energy.

The early patents on ultrasonic sound detectors are reported to have appeared in the early 1940s and may, in part, have been inspired by the need for detectors for the construction and testing of large vessels during World War II. One of the first wartime applications was testing for flaws and de-laminations in the armored plating of tanks. It is likely that the technology was applied to the inspection of ships, as well.

Since the 1920s, Elmer Sperry had been involved with the detection of transverse defects in rail tracks, but it became apparent, as the science improved, that there could be many other types of defects that were not easily discovered with magnetic probes. Floyd Firestone and Elmer Sperry subsequently developed the 'supersonic reflectoscope,' which is essentially an ultrasonic flaw-detector, to detect internal discontinuities in industrial materials. Sperry continued over the decades to develop industrial products and Sperry reflectoscopes are now commonly used for inspecting materials and welds.

The invention of transistors, in 1947, contributed substantially to the development of smaller, more sophisticated, lower-power-consumption electronics devices. Other inventors became interested in the commercial potential of industrial detectors.

In Germany, after the war, inventors returned to peacetime inventions. Karl Deutsch, who rose to leadership in the field of industrial flaw detection, read a journal article about the reflectoscope and subsequently asked a young radio operator with electronics skills to build an ultrasonic flaw-detector similar to the reflectoscope. Before Branscheid completed the engineering task, other German inventors, Josef and Herbert Krautkrämer, announced that they had developed a similar device. In spite of the competition (or perhaps because of it), Deutsch continued his work, branching into other areas.

By the late 1940s, pulse-echo metal flaw-detectors had been developed in Germany by the Krautkrämers. The early models were gradually improved to operate at higher frequencies, with shorter pulse durations. These advancements helped improve the resolution of the devices and the reputation of the Krautkrämer company.*

Deutsch and Branscheid continued their work and developed an instrument called the Echograph, introducing it commercially in 1951. A patent dispute developed between the Echograph and the Sperry-reflectoscope, which was brought out in 1952. The Karl Deutsch company shifted its focus to other products, introducing the RMG in 1957, an instrument designed to measure crack depth. The Echograph was updated with new transistor technologies, resulting in a modular version that was designed for use with ultrasonic systems.

When sound detectors were first introduced, operators had to learn to interpret the acoustic information and to equate differences in pitch (frequency) and the pattern of echoes to make any sense of the data. As technologies began to move into ultrasonic frequencies, it was

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*The Krautkrämers subsequently wrote "Ultrasonic Testing of Materials." The 4th edition was published in 1990 by Springer-Verlag.

no longer possible to interpret the data auditorily unless the frequencies were brought down into auditory ranges. Fortunately, the development of cathode-ray tubes (CRTs) made it possible to visualize the acoustic information. The only problem was that early CRTs featured low resolution, monochrome images, slow refresh rates, and a tendency to get 'out of tune;' in other words, they had to be adjusted all the time. Since it was difficult to capture the images on film by photographing the screen, more direct ways of installing a photographic camera were devised, and images of ultrasonic data were available by the mid-1950s.

In 1956, the pioneer C-scan images were created at the Automation Instruments Power Plant Inspection Division test lab with the Hughes Memotron. This large industrial instrument incorporated photographic imaging capabilities with sound pulse/receiver units.

Industrial Flaw-Detection

Since his initial work in the 1920s, Sperry had continued to tackle the challenge of rail line inspection.

Trolleys, trains, and cable cars were widely used throughout North America and Europe in the 1950s and it was important to inspect and maintain the tracks to ensure public safety. In 1959, the New York City Transit Authority (NYCTA) installed a Sperry Rail track-inspection car based entirely on ultrasonics.

'Portable' flaw detectors were being devised now as well, by both Sperry and Automation Instruments. The transition from tubes to transistors was making it possible to create instruments one-tenth the size of their vacuum-tube counterparts, but true miniaturization didn't emerge until the late 1960s and 1970s when microelectronics had a significant impact on both the size and processing capabilities of these industrial flaw-detecting machines.

Nuclear Science and International Regulations

Most of the acoustic surveillance technology in the early 20th century was focused on sonar and industrial ultrasonics, though seismic technology was being developed as well.

In 1945, at the end of World War II, the United States dropped atomic bombs on the cities of Hiroshima and Nagasaki. This provoked the development and test detonation of a Soviet atomic bomb in August 1949. The Arms Race had begun and concern was raised about the proliferation of atomic weapons and the means to detect their presence.

In the early 1950s, seismic stations to detect atomic explosions were installed in strategic locations, including Alaska, Germany, Greenland, Korea, and Turkey. Other technologies to detect radiation and atmospheric changes were also developed.

Up to this point, ultrasonic technologies were primarily analog, but this was about to change. In 1973, the Karl Deutsch company introduced the first digital ultrasonic flaw detector, called the Echotest.

Nuclear energy is not used only for building bombs. It is also used to power generators and to create explosions for geological surveys and resource exploration. Seismic measurements from various types of explosions are sometimes used to study geological formations. Unfortunately, the fallout and waste from nuclear explosions can have deadly consequences for plant and animal life, including death, radiation burns, some forms of cancer, immune-system damage, and a host of lesser health problems. The difficulty of disposing of nuclear wastes or avoiding nuclear fallout (radioactive particles) is part of the reason for international restrictions on nuclear testing and global surveillance of nuclear weapons development.

In May 1974, India exploded a "peaceful" nuclear device that was estimated on the basis of seismic and visual surveillance, to be about five kilotons or less (about half that announced by India). The Threshold Test Ban Treaty instituted that year set a limit of 150 kilotons for nuclear testing.

Technological Developments

At the end of 1974, the Altair desk-sized computer kit was introduced to hobbyists. Within two years, the microcomputer revolution was in full swing, forever changing electronics in dramatic ways. Microcomputer electronics were soon incorporated into a wide range of sensing devices including acoustic and seismic wave detectors.

In 1976, the Group of Scientific Experts (GSE) was given a mandate to study the scientific basis for monitoring a test-ban treaty from the CCD (now known as the Conference on Disarmament). The GSE was selected for this task on the basis that it had done a lot of scientific groundwork on seismic monitoring. The data would be transmited, via satellite, to the International Data Center (IDC).

In 1976, the Karl Deutsch company, which had become a recognized leader in industrial detection technology, introduced a computer-controlled ultrasonic flaw-detecting system, called the Echograph 1160.

Ultrasound technologies for industrial testing and medical imaging continued to improve in the late 1970s and early 1980s. Microprocessors were now starting to be used in many electronics devices. The Karl Deutsch Echograph 1030, a microprocessor-controlled ultrasonic flaw detector, was introduced in 1983, in Moscow. The following year, the Echometer 1070 was demonstrated, equipped with a microprocessor-controlled ultrasonic thickness gauge. In 1987, Karl Deutsch, still a leader in industrial ultrasound technology, added more sophisticated data processing capabilities to its systems. By the early 1990s, improved very-large-scale-integration (VLSI) made it possible to produce smaller, more powerful detectors and portable versions of the industrial models.

From the time of the early ultrasonic reflectoscopes that were used for rail inspection, Sperry had also been continually improving and upgrading its products. The ultrasonic C-scanner was available in the 1980s, along with higher-end versions of the product with computer control and color display capabilities.

Digital seismographic instruments were becoming more prevalent by the mid-1980s, and the technology continued to improve, with low-noise seismometry, higher-bandwidth data rates, greater storage and processing capacities, and the increased ability to communicate through satellites and computers.

Political Policies and Technology

The United States sometimes sets domestic policies and carries out research that appear to contradict its foreign policies. At a time when the U.S. was seeking to monitor and suppress nuclear proliferation in other nations, it was also proposing internal testing procedures that could obscure America’s own nuclear explosions. In the early 1980s, work in U.S. labs included design ideas for underground nuclear test facilities which could contain large-scale explosions to minimize the seismic impact, described by some as a ‘quiet’ bomb-testing installation where tests could be carried out without alerting the rest of the world. At that time and since, there have been many American initiatives for exposing, monitoring, and suppressing foreign weapons facilities, exposing the irony of the position of the U.S. Government with regard to quiet testing.

Supercomputers were emerging in the 1980s, providing new ways to compile and analyze complex data from multiple sensing stations. Powerful computers introduced new industrial testing and simulation capabilities as well. The improvement in computing technology made it possible for some aspects of nuclear testing to be simulated, providing developed nations with a means to carry out weapons some aspects of research with fewer actual detonations, options which some countries don't have.

In the early 1990s, the concept of 'nonlethal weapons,' began to get attention in political circles and in the press. Weapons designed to stun or disable, rather than kill, have been available as consumer items since about the 1980s and are regularly shown on science fiction series such as Star Trek™, but the use of these on a large scale was not given substantial attention until technologies improved enough to provide a great many more options. The development of lasers, electromagnetic-pulse devices and infrasound technologies made a broader range of nonlethal weapons possible.

On the one hand, there are definitely situations in which it is better to disable and apprehend than to kill. Fleeing criminals, wild animals loose in populated areas, and marauding forces are all examples in which nonlethal weapons can be a humane solution. On the other hand, some types of nonlethal weapons can do subtle, perhaps cumulative harm that is difficult to document and prove and thus difficult to trace to the time of the event or the persons responsible. There is no smoking gun in nonlethal attacks. Like chemical warfare, nonlethal warfare in the wrong hands is potentially one of the most frightening and horrific adaptations of science and should not be pursued without the most stringent of ethical judgments. Opponents to nonlethal weapons, which include certain infrasound devices, began to speak out against the technology in the early 1990s.

Global Monitoring

In May 1955, the Soviet Union proposed a ban on nuclear testing, initiating a process of negotiation that would span many decades. Some of the other key players were the United States, France, and Great Britain. In 1957, the Soviet Union made further suggestions for prohibitions that included international supervision of the process. In March 1958, the Soviet Union made an announcement that it would be discontinuing nuclear tests, with appeals to other superpowers to follow suit.

In the summer of 1958, the "Conference of Experts on Nuclear Test" convened in Geneva, Switzerland, to discuss issues related to the monitoring of a ban on nuclear tests. Confirmatory on-site inspections were also discussed to distinguish natural events from human-initiated explosions.

Beginning in 1959, the U.S. Air Force's Project VELA Program involved the installation of a major global network of seismographic stations, called the World-Wide Standard Seismological Network (WWSSN). This contributed substantially to the geosciences, especially plate tectonics, and created a new body of data from global monitoring. It also provided a means of detecting signs of nuclear detonations that could be instrumental in international monitoring.

In 1963, the Limited Test Ban Treaty (LTBT) was negotiated and subsequently signed and put into force. It prohibited nuclear explosions in the atmosphere, under water, or in outer space. Underground tests that might result in the spread of radioactive products were also banned.

In 1976, the Conference on Disarmament (CD) established the Ad Hoc Group of Scientific Experts (GSE), to develop and evaluate cooperative international actions toward enforcement of the Comprehensive Test Ban Treaty. The GSE has since been involved in the development of networked data-exchange systems and technical tests related to seismic monitoring.

Treaty Ratification and Enforcement

Despite disagreements, disarmament talks appeared to have gotten off to a reasonably good start in the 1960s and 1970s, especially on the issues of nuclear testing. But then, somehow, the negotiations dragged on. Large countries continued to develop new technologies that could conceivably be used as weapons, even if that was not the original intention of the technologies. Smaller countries continued to try to improve their weapons capabilities and were gradually arming themselves with nuclear capabilities. The Soviet Union collapsed and turmoil broke out in the nations bordering Russia and economic havoc descended on the former U.S.S.R. By the 1990s, disarmament had not come as far as people had hoped and the threat of nuclear war or terrorism in smaller nations increased. Progress in nuclear technology in China led to testing and the rest of the world relied on surveillance technologies to monitor the magnitude and progress of the testing activities.

In 1992, China conducted nuclear tests in May. The site location was recorded, a month after the blast, by the U.S. Landsat-4 imaging satellite. The aerial images suggested that the Chinese had prepared two test sites. Further nuclear tests were conducted by the Chinese Government in September. Seismic surveillance technologies, in conjunction with other data, were used to estimate the extent of the explosions.

Around this time, commercial satellite companies began marketing high-resolution images from Russian satellites. The resolution of commercial imagery at this time was sufficient to detect trucks and buildings (more information on satellite capabilities is described in the Aerial Surveillance chapter).

In October 1993, China is reported to have conducted an underground nuclear explosion at their Lop Nur test site. The Verification Technology Information Center (VERTIC) announced details of the test based on a variety of surveillance technologies and analyses, describing the range, location, and shaft orientation of the detonation. The conclusion that it was a nuclear explosion was based in part on the absence of surface waves, the 5.8-magnitude reading on the Richter scale, and surveillance monitoring of China's activities over the last several years. The news was communicated globally within the next couple of hours.

The results of the various reports of the nuclear test appeared to confirm that the global seismic network was suitable for monitoring larger-scale nuclear testing activities.

Progress in Disarmament and International Monitoring

By early 1996, the members of the Conference on Disarmament were making progress toward an international treaty on various weapons and surveillance technologies, primarily nuclear armaments, but there had also been discussion of an international network of seismic stations supplemented by a larger number of auxiliary stations. Networks of hydroacoustic and infrasound sensors were agreed to by most nations, while satellite data were still under discussion.

In May 1997, the international community was startled to discover that India had conducted nuclear tests. The limitations of seismic-sensing technologies were demonstrated when the nature and scope of these tests were not detected unequivocally by the *Comprehensive Test Ban Treaty* (CTBT) monitoring system, leading to concerns about enforcement of the treaty. It was known that explosions rated at less than one kiloton might be difficult to detect from a distance, but this was the first politically sensitive, unsettling occurrence that underlined limitations of both the technology and political process. In addition to the scientific ramifications, there were questions about whether the system should even be monitoring a country that was not yet party to the Treaty.

It's difficult to know what you have or haven't detected without concrete reference information. Controlled scientific tests can yield exact data. Observations and calculations based on second-hand information and carefully worded announcements from foreign nations are more difficult to assess. In a post-blast statement, the Prime Minister of India announced that a 43-kiloton thermonuclear device, a 12-kiloton fission device, and a 0.2-kiloton device had been detonated. India's leader stated that the 12- and 43-kiloton detonations were about a kilometer apart.

Initial data from the Incorporated Research Institutions for Seismology seemed to suggest only one event, with an estimated detonation that fell somewhere between the two larger devices, around 20-kilotons, from one source or simultaneous multiple sources very close together. This raised questions both as to the veracity of the political leader's statements and to the accuracy of readings and interpretation of seismic data.

Later data from more than 100 sources yielded evidence of a slightly larger magnitude, leading to estimates that the blast was about 30 kilotons, which still didn't match verbal reports from India. Seismic measures of the blast from different stations that reported to the International Data Center recorded magnitudes ranging from 4.7 to just over 5.0 which would indicate a blast of not much more than 15 ± 10 kilotons.

The Air Force Technical Applications Center (AFTAC) was commissioned to install twenty new seismic arrays around the world between 1997 and 2001, with the first to be installed in Peleduy, Russia, for operation by Russia's Special Monitoring Service. Data from these arrays would be scheduled to arrive at the IDC within one minute of their acquisition.

AFTAC was also planning the installation of new hydroacoustic arrays and a network of infrasonic arrays in the southern hemisphere to aid in CTBT monitoring.

In August 1997, a 'seismic event' in Russia stirred controversy over whether Russia had violated the CTBT and detonated a small nuclear explosion or whether the event was an earthquake. A seismic sensing array in Norway had picked up the ambiguous vibrations. This occurrence was significant in that it tested the global surveillance system's ability to pick up smaller events and whether it could distinguish between natural and human activities. The data gathered suggested it is not likely that it was a nuclear explosion, as it appears to have occurred out in the Kara Sea. That is not to say a nuclear test could not be carried out in this unlikely location; the Indian Sea is thought to have been the site for a possible earlier nuclear test explosion. But the body of data, taken as a whole, suggests it was a natural phenomenon.

By November, the U.S. Central Intelligence Agency (CIA), had released an assessment of the event, with input from outside experts, which stated that the event was not a nuclear explosion.

Nuclear weapons proliferation is a form of one-up-manship. The development of the U.S. atomic bomb was in response to rumors that the Germans were developing such a weapon during World War II. If indeed they were, the project was never successfully completed. In response to the U.S. detonation of two bombs in Japan, the Soviets set about creating their own 'atom bomb.' When India conducted nuclear tests in August 1997, neighboring Pakistan responded by conducting their own tests near the border of Afghanistan in May 1998. The Pakistan government claimed that five devices had been detonated. Seismic surveillance did not pick up five detonations and some think only one may have been detonated.

Assessments of nuclear detonations using a variety of surveillance technologies and human intelligence resulted in estimates that the U.S. and the Soviet Union had been responsible for about 85% of the nuclear detonations that had occurred up to this time. The total numbered over 2,000, about 26% of which were atmospheric explosions [Norris and Arkin, 1998].

In 1997, the Comprehensive Nuclear Test-Ban Treaty Implementation Act was put before the Canadian House of Commons to define Canada's obligations under the Treaty. The duties and functions of the National Authority included radionuclide monitoring, seismological monitoring, hydroacoustic monitoring, and infrasound monitoring. The Minister of Natural Resources was given responsibility for coordinating and, if necessary, operating verification measures as part of the International Monitoring System (IMS) "by means of seismological, hydroacoustic and infrasound monitoring."

By 1998, the CTBT had established guidelines for international monitoring that would include hydroacoustic monitoring and infrasound monitoring. The system was organized so that the data from these surveillance technologies would be collected and transmitted to an International Data Center (IDC) located in Vienna, Austria. Data could also be provided by nations through separate arrangements that were not formally within the IMS. Each party in the treaty would be provided with all data transmitted to the Data Center. The U.S. National Data Center would be responsible for consolidating the U.S. data contributed to the IDC as well as disseminating data from the IDC which would then be made available to government agencies and academic researchers.

By 1999, the U.S. was coming under international and domestic criticism for not having ratified the Comprehensive Test Ban Treaty (CTBT). Submitted for ratification by the Clinton administration in 1997, it was reported to have been held up by Foreign Relations Committee Chair Jesse Helms until he was given protocols for both the Anti-Ballistic Missile Treaty and the Kyoto Climate Change Treaty, which he is reported to oppose [Collins and Paine, 1999]. As a superpower, many smaller nations take their lead from the U.S. in treaty matters.

An international CTBT conference was scheduled to seek ways to move the Treaty into completion. At this point only Britain and France had ratified the Treaty, just two out of the 44 nuclear-capable nations that were needed before the Treaty could be in force.

5. Description and Functions

General descriptions and functions of acoustic devices are described in Chapter 2 and Chapter 4 and are not repeated here. The introductory sections of this chapter provide a good overview of the technologies, and the following Applications section rounds out the picture. Further information can be sought from the resources listed at the end of the chapter.

It was mentioned in the introduction that acoustic waves and shock waves are not the same. However, the devices that detect acoustic waves can be similar to those that detect shock waves, so this chapter hasn't made a strong distinction so far between shock waves and acoustic waves. However, in scientific circles, the two phenomena are considered distinct from one another.

Acoustic waves are *longitudinal*; that is, the vibrations occur in the same direction as the motion of the waves. (Electromagnetic waves, in contrast, are *transverse* waves.) The molecules that make up the acoustic medium, whether it's air, water, or some other elastic substance, will go through a series of compressions, with the particles alternately crowding together, and decompressions, where they 'relax' back into their previous positions. The particles in denser materials (wood, metal) generally resume their normal positions and less dense materials (air, water) tend to return to a similar state of relationships or equilibrium, if not the exact same positions, after the wave has passed through the medium.

Shock waves tend to be created by sudden, violent events, such as explosions, earthquakes, lightening strikes, and volcanic eruptions. (Strong acoustic waves are often generated by the same events at the same time, which is one of the reasons why they tend to be studied and measured together.)

A shock wave is a sudden violent pressure wave in an elastic medium (water, air, soil, etc.). Shock waves tend to travel faster than acoustic waves, but their intensity also tends to decrease more quickly as the heat generated by the wave is absorbed by the elastic medium. As shock waves die down, they lose intensity and the high pressure wavefront diminishes. It becomes difficult to distinguish them from events that originated as acoustic waves.

Some people claim that the difference between an acoustic wave and a shock wave is not so much a difference in the basic aspects of the phenomena, but rather a difference in intensity. In other words, some references will call a shock wave a high-intensity acoustic wave. Physics texts describe a shock wave as different in character from an acoustic wave. It consists of a conical wavefront that is produced when the *source velocity* exceeds the *wave velocity* of the wave.

From a visual point of view, a shock wave can sometimes be seen in a solid medium. (If you're close enough to see it, it's usually a good idea to leave, quickly.) If you have ever seen video footage of a violent explosion, you may have seen a shock wave. The effect is remarkable. If the ground is fairly flat and unpopulated, you can see it buckle up in waves that look as though a huge rock was thrown into the center of the 'pond,' except that the pond is sand or gravel or some other solid, elastic base that doesn't ordinarily move like water.

Shock waves move very quickly and disappear very quickly. Meanwhile, the acoustic rumbles from the explosion might reach you after the shock wave has knocked you right off your feet. In some cases the acoustic wave might never reach you, even if you feel the shock wave, because the sound may travel up and out. When Mt. St. Helen's in Washington State exploded in a volcanic eruption in 1980, many people 20 miles from the volcano didn't hear a thing, but were covered in ash from the eruption, while other people almost 200 miles away didn't see any ash, but heard the explosion so loudly it sounded like a large bomb exploding. Those who couldn't hear the explosion, even if they were nearby, are said to have been within the *cone of silence*, the region not affected by the acoustic waves.

Shock waves don't just travel through the ground, they may travel through air as well. When jets fly at supersonic speeds (faster than the speed of sound) they build up tremendous pressure on their forward surfaces, particularly on the wings and the tail. When they break through the *sound barrier*, there are significant shock waves and a loud 'sonic boom.'

For the purposes of an introductory text, the distinctions aren't as important as they are in scientific research, but it is a good idea to remember that seismic detectors and acoustic detectors are intended to record phenomena that are similar, but not exactly the same.

6. Applications

Low- and high-frequency acoustic waves and shock waves have many applications in surveillance. They have also been tested for their weapons capabilities, but these are only mentioned briefly as they are not directly concerned with surveillance and, in fact, the purpose of many surveillance devices is to detect and prevent the use of weapons or harm that might result from their use.

Historically, ultrasound transducers required a liquid contact, but more recently air-coupled transducers, developed by Dr. Schindel at Queen's University in Canada, and Dr. Hutchins at Warwick University in England, have improved to the point that many new sensing applications, particularly for industrial environments, are now possible.

Structural Assessment and Quality Assurance

In industrial applications ultrasound is used for non-destructive testing (NDT) and examination of materials, often in conjunction with other surveillance technologies, including infrared thermography and radiography. Ultrasound was found to be able to make a deeper assessment of some types of structures in some materials. Impact detection, cracking, and delamination are just some of the defects that may be detected with ultrasound. Ultrasound is favored for many applications because it does not require immersion or contact with the materials. The newer ultrasound technologies are beginning to replace some of the more expensive radiographic and computer tomography detectors for industrial applications.

Ultrasonic inspection of cracks, seams, and defects is now widely carried out in industrial manufacturing and quality assurance programs. By selecting specific types of transducers and arranging them in different ways, it is possible to gather data on a large variety of types of defects. Pulse-echo and pitch-catch are just two of the techniques that can be used. Industrial weld examinations are typically done at frequencies of 2.25 or 5.0 MHz.

Weather and Disaster Prediction and Monitoring

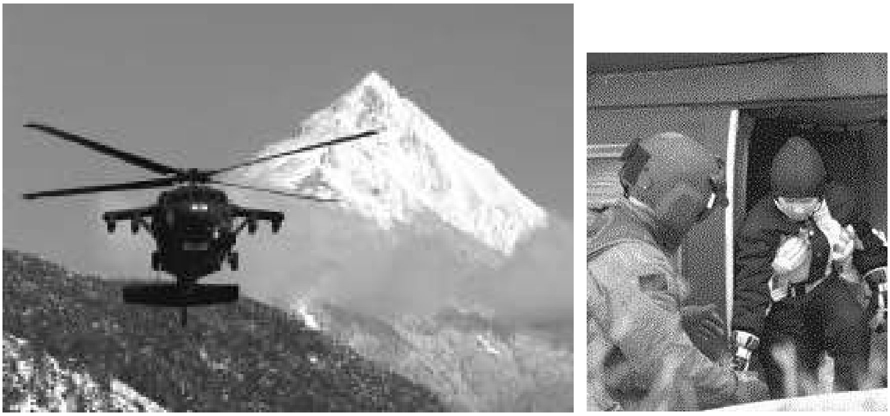
Seismographic detectors are often used in conjunction with Doppler radar weather imaging systems to predict the occurrence and magnitude of natural disasters, including earthquakes, floods, and volcanic eruptions. Left: A Pave Low IV helicopter about to refuel over severely flooded Central Mozambique, in March 2000. The U.S. military contributed to relief efforts after torrential rains and floods. Right: Spc. Rodney Porter unloads a shaken dog that was rescued from flood waters caused by Hurricane Floyd in September 1999. The National Guard provided humanitarian relief for people devastated by the hurricane. [U.S. DoD news photos by Cary Humphries and Bob Jordan, released.]

Infrasound is used for detecting and measuring earthquakes, tidal waves, volcano eruptions, explosions, large weather systems, and floods. The information can be applied to disaster prevention and relief and search and rescue efforts in a diverse number of situations.

The ‘weather’ outside our atmosphere is also monitored by a number of technologies including infrasound. When the Earth is hit by meteors we often notice their presence from the sparkles of light that occur when they fall to Earth and burn up in the atmosphere. During the day, however, it is harder to see these events, particularly if the meteors are small. Infrasonic vibrations from the disturbance can sometimes reveal their presence.

Avalanche Detection

With so many more people taking to the mountains for sports and sightseeing, avalanche prediction and detection are increasing concerns for park personnel and search and rescue professionals. Infrasonic instruments that continually monitor the ambient vibrations are used to detect avalanches and slides and communicate that information to the appropriate station, including the magnitude of the disturbance, the location, date, and time. The effective range of these systems varies with conditions and the local geography, but can reach up to about five kilometers.



Infrasound detectors are now used in many regions to predict and detect avalanches and rock slides. Here, a U.S. Army Blackhawk helicopter comes in for a landing after rescuing avalanche victims (right) who were stranded on a mountain in Austria in February 1999. [U.S. DoD news photos by Troy Darr, released.]

Collision Avoidance

One of the newer adaptations of infrasound is in guidance control and safety systems to aid in preventing collisions. Low-level sound vibrations at times or in environments where the vibrations shouldn't occur can serve as advanced-warning systems or as grounds security monitors. Infrasound has even been proposed as a means of reducing bird-aircraft collisions.

Communications Security

In efforts to make communications more secure, a number of technologies to change or scramble voices or to create confusing noise have been developed. Ultrasound is one of the means that has been used to disrupt microphones (such as pocket recorders or bodyworn wires), with mixed results. Effectiveness may depend on the type of microphone that is being used and the ability of the conversants to tolerate the ultrasound which can cause nausea and general malaise even if it can't be heard.

Grounds Security

There are many ways in which infrasound can be used in commercial, military, and personal security applications. Infrasonic ground vibrations can signal the presence of vehicles or foot traffic, the movement of air can indicate opening doors, windows, or drawers. If the sensor is triggered it can sound an alarm or turn on a microphone or video surveillance device. Infrasound burglar alarms are available for about $35. Ultrasonic applications for security are now increasing as well, with newer air-conducting ultrasonic technologies that are suitable for distance-sensing, room surveillance, and robotic imaging.

Ultrasound is sometimes combined in the same housing with infrared sensors. This combination can reduce the incidence of false alarms.

Ultrasound has been used along with infrared in guidance systems for autonomous robots designed for patrol and grounds security. Higher frequencies tend to provide more accurate assessments of distance in robotic navigation applications.

Microphonic Monitoring

Microphones designed to monitor sounds within and without human hearing ranges have become increasingly small, inexpensive, and powerful.

In September 1999, New Scientist reported that Emkay in West Sussex had developed a broadcast-quality microphone so tiny it would fit into a 2.5 millimeter cylinder. This broadband microphone can record ultrasound as well as audible sound, making it suitable for surveillance and wildlife research applications.

Medical Applications

Ultrasound allows internal biological structures to be detected and imaged in realtime and thus is highly valuable to the medical industry. The denser areas of cartilage and bone and some of the organs will show up more readily than fluid-filled cavities and tissues. Ultrasound is used to detect, assess, and monitor fetal development and a variety of disease conditions including heart disease, diabetes, and cancer.

Sandia Laboratories have developed some powerful three-dimensional ultrasound technologies that allow CAD and acoustic technologies to enhance one another to create detailed images that reveal internal structures in relation to one another. Three-dimensional ultrasound systems can be used in industrial non-destructive evaluation and testing, mine and bomb detection, and medical diagnostic imaging and prosthesis evaluation and fabrication.

Rail Inspection

Rail lines are subjected to great weights and temperature changes and require constant inspection and maintenance. Rails are now surveilled with a combination of ultrasound and electromagnetic sensors. The electromagnetic equipment tends to be bulkier than the sound-sensing equipment. These detection systems are usually housed in self-contained rail-inspection cars, with the probes mounted between the axles. Rail-inspection trucks are also used, but generally carry only the ultrasonic detectors.

Detection probes on moving conveyances can only move as fast as the technology can keep up with the data. For this reason, most sonar depth sounders have upper speed limits of about 20 knots and imaging systems rarely go above 1 to 4 knots depending on their resolution and sophistication. Rail inspection follows similar principles, with detection devices being moved along at speeds of up to about 12 ± 3 kilometers per hour.

Robotics Sensing

The Polaroid 6500 Ranging Module is an economical ultrasonic sensor that is used in many hobby and commercial ranging applications, especially for longer-range robot navigation. Distance-calculation is not carried out by the Module, but can easily be calculated with interfaced microprocessors.

Weapons Detection

There are many detectors now used on public transportation systems to prevent possible harm from weapons and bombs. Airlines now regularly use X-rays and magnetic detectors. Ultrasound sensors are now being developed to remotely detect and image concealed weapons. For example, support from DARPA and the Concealed Weapons Detection Technologies grant program has resulted in the creation of an ultrasound detector that can detect both metallic and nonmetallic weapons under clothing up to a distance of about 5 to 8 meters. Information is available through http://www.jaycor.com.

7. Problems and Limitations

Passive infrasound, ultrasound, and seismic detectors do not pose any direct risks to physical structures or human health, since they are designed to detect rather than generate acoustic waves and shock waves. However, *active* infrasound and ultrasound are not completely harmless technologies. Most active acoustic technologies do not emit high intensity sound waves and have a low probability of doing harm, but since they involve generating an acoustic pulse that cannot be heard by humans and which can be emitted at high intensities, they must be used with a certain amount of caution.

Prior to the use of ultrasound for prenatal care, X-rays were sometimes taken of the fetus if the mother or fetus were determined to be at risk. The risk of using ultrasound for surveilling the womb to determine the health of the fetus is less than that of X-rays but is not known to be 100% safe. Many medical decisions are based on trade-offs. The risk of taking an ultrasound reading is considered to be much less than the risk of taking an X-ray. Taking an ultrasound reading is also considered to be less of a risk than not taking an ultrasound reading, as it is a valuable means to monitor the health and progress of a fetus.

Since infrasound has been evaluated as a potential weapon with the possibility of creating cardiac, respiratory, nervous system, or digestive system dysfunctions, it is clear that the application of the technology may not be safe in all circumstances, but generally, infrasound and ultrasound technologies are more beneficial than harmful.

8. Restrictions and Regulations

There are not a lot of regulations explicitly prohibiting or restricting the uses of infra/ultrasonic technologies for surveillance purposes, except perhaps in the medical industry, where it is used to assess fetal health and a variety of illnesses. The main concerns in industrial environments are monitoring the intensity of the acoustic waves and the provision of proper ear protection and education on the potential damage that can occur if protection is not worn.

The American Institute of Ultrasound in Medicine releases reports on a variety of subject areas including information on the medical use of ultrasound, safe usage guidelines, cleaning recommendations, and possible hazards. http://www.aium.org.

9. Implications of Use

The main concern in the use of infrasonic and ultrasonic technologies is keeping the intensity of the sound emanations to levels that are low enough to prevent damage to living tissues and to avoid prolonged exposure.

There has been very little controversy regarding the use of infrasound, ultrasound, and seismic detection technologies for surveillance. The two major concerns are the correct use of medical imaging for monitoring a growing fetus and the avoidance of high-intensity sound waves for military applications that may disrupt the hearing and health of marine animals.

10. Resources

Inclusion of the following companies does not constitute nor imply an endorsement of their products and services and, conversely, does not imply their endorsement of the contents of this text.

10.a. Organizations

Acoustical Society of America (ASA) - ASA is an international scientific society dedicated to research and dissemination of knowledge about the theory and practical applications of acoustics. ASA sponsors annual international meetings and annual Science Writers Awards for articles about acoustics. http://asa.aip.org/ http://www.acoustics.org/

The Federation of American Scientists (FAS) - A privately funded, nonprofit research, analysis, and advocacy organization focusing on science, technology, and public policy, especially in matters of global security, weapons science and policies, and space policies. Sponsors include a large number of Nobel Prize Laureates. FAS evolved from the Federation of Atomic Scientists in 1945. The site contains numerous surveillance, guidance systems, U.S. Naval documentation, and other radar-related information. http://www.fas.org/index.html

Incorporated Research Institutions for Seismology (IRIS) - This is a consortium of almost 100 research facilities, most at universities with strong research interests in seismology. It includes the Data Management System, which consolidates data from the collection centers conducting seismic recordings that make up the Global Seismographic Network (GSN). http://www.iris.washington.edu/

International Monitoring System (IMS) - This is a primary seismic network of stations that are designed to detect, locate, and identify underwater and underground events. There are also auxiliary stations contributing data to this system.

Naval Command, Control and Ocean Surveillance Center (NCCOSC) - Established in 1992, this center operates the Navy's research, development, testing, engineering, and fleet support for command, control, and communications systems and ocean surveillance. NCCOSC reports to the Space and Naval Warfare Systems Command. http://www.nswc.navy.mil/

Naval Research Laboratory (NRL) - The NRL conducts multidisciplinary programs of scientific research and advanced technological development of maritime applications and related technologies. The NRL reports to the Chief of Naval Research (CNR).

Naval Surface Warfare Center (NSWC) - Established in 1992, this center operates the Navy's research, development, testing, and fleet support for ship's hulls, mechanical, weapons, and electrical systems. NSWC reports to the Naval Sea Systems Command. http://www.nswc.navy.mil/

Ocean Mammal Institute (OMI) - A public awareness, research, and educational organization for the study and preservation of marine mammals. The Web site includes an information page on low-frequency active (LFA) sonar and its possible effects on marine life. http://www.oceanmammalinst.com/

Ultrasonics Industry Association (UIA) - A trade forum for manufacturers, users, and researchers in ultrasonic technology. The site includes descriptions of practical applications of ultrasonics, conference information, and other links. http://www.ultrasonics.org/

U.S. Office of Naval Research (ONR) - The ONR coordinates, executes, and promotes the science and technology programs of the U.S. Navy and Marine Corps through educational institutions, government labs, and a variety of organizations. ONR carries out its mandates through the Naval Research Laboratory (NRL), the International Field Office, the Naval Science Assistance Program (NSAP), and the Naval Reserve Science & Technology Program. ONR reports to the Secretary of the Navy and is based in Arlington, VA. http://www.onr.navy.mil/

U.S. Space and Naval Warfare Systems Command (SPAWAR) - This department designs, acquires and supports systems for the collection, coordination, analysis and presentation of complex information to U.S. leaders. http://agena.spawar.navy.mil/

10.b. Print

Hughes, Thomas Parke, “Elmer Sperry: Inventor and Engineer,” Baltimore: Johns Hopkins University Press reprint, 1993, 348 pages. Sperry was one of the early pioneers in the development of ultrasonic detectors for industrial purposes.

Krautkrämer, Josef and Herbert, “Ultrasonic Testing of Materials,” New York: Springer-Verlag, 1990 (reprint). The authors are pioneers of ultrasonic flaw-detection devices and Krautkrämer is now one of the largest companies in the industry.

Needham, Joseph. Needham wrote a series of books in the 1950s and 1960s on technology, industry, and science in China, published by Cambridge University Press in Cambridge. The topics include clockworks, metal construction, and chemistry. They also include discussions of technological information exchange between China and the western nations. Some of the volumes have been recently reprinted in shorter versions.

Sontag, Sherry; Drew, Christopher, “Blind Man’s Bluff: the Untold Story of American Submarine Espionage,” New York: Public Affairs, 1998, 352 pages. Describes the Cold War submarine ‘chess game’ between the superpowers, the U.S. and the Soviet Union.

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McHugh, R.; Shippey, G.A.; Paul, J. G., “Digital Holographic Sonar Imaging,” *Proceedings IoA*, V.13, Pt. 2, 1991, pages 251-257.

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Richards, Paul G., “Seismological Methods of Verification and the International Monitoring System,” Lamont-Doherty Earth Observatory of Columbia University. This describes general background on seismology and test ban monitoring and describes steps that can be taken to carry out the monitoring for the Comprehensive Test Ban Treaty.

Shirley, Paul A., “An Introduction to Ultrasonic Sensing,” *Sensors, The Journal of Machine Perception*, Nov. 1989, V.6(11). Describes ultrasonic ranging and detecting devices that work in air and the various environmental factors that can influence the signal.

Smurlo, R. P.; Everett, H. R., “Intelligent Sensor Fusion for a Mobile Security Robot,” *Sensor,* June 1993, pages 18-28.

Thurston, R. N.; Pierce, Allen D., editors, “Ultrasonic Measurement Methods,” *Physical Acoustics,* V.XIX,” Academic Press, 1990.

U.S. Congress, Office Technology Assessment, “Seismic Verification of Nuclear Testing Treaties, OTA-ISC-361,” U.S. Government Printing Office, Washington, D.C., May 1988.

Journals

“Bulletin of the Atomic Scientists,” this professional journal includes references to infrasonic detectors. http://www.bullatomsci.org/

“Bulletin of the Seismological Society of America, “ bimonthly professional journal.

“The e-Journal of Nondestructive Testing & Ultrasonics,” available from NDTnet. http://www.ndt.net/v05n06.htm

“European Journal of Ultrasound,” official journal of the European Federation of Societies for Ultrasound in Medicine and Biology. http://www.elsevier.nl/inca/publications/store/5/2/4/6/3/7/

“International Network of Engineers and Scientists for Global Responsibility Newsletter,” published in Germany, this provides information on various scientific and NATO activities.
http://www.inesglobal.org/

“Ultrasonic Imaging,” published by Academic Press, available online up to 1996.
http://www.idealibrary.com/cgi-bin/links/toc/ui

10.c. Conferences and Workshops

Many of these conferences are annual events that are held at approximately the same time each year, so even if the conference listings are outdated, they can still help you determine the frequency and sometimes the time of year of upcoming events. It is very common for international conferences to be held in a different city each year, so contact the organizers for current locations.

Many of these organizations describe the upcoming conferences on the Web and may also archive conference proceedings for purchase or free download.

The following conferences are organized according to the calendar month in which they are usually held.

“IEEE International Conference on Acoustics, Speech and Signal Processing,” San Diego, Ca, Mar. 1984.

“ICASSP2000,” 25th International Conference on Acoustics, Speech, and Signal Processing, Istanbul, Turkey, 5-9 June 2000.

“New Millennium–New Vision for Ultrasonics,” 30th annual symposium, Columbus, Ohio, 12-13 June 2000.

“Review of Progress in Quantitative Nondestructive Evaluation Conference,” Snowbird, Utah, 19 July 1998.

“Ultrasonic Transducer Engineering Conference,” Pennsylvania, 2-4 Aug. 2000.

“ICANOV2000,” International Conference on Acoustics, Noise, and Vibration,” Montreal, Canada, 8-12 Aug. 2000.

“International Conference on Ultrasonics and Acoustic Emission,” 35th annual conference, Czech Republic, 14-18 Sept. 1998.

“Ultrasonics International Conference,” current information not available, but conference proceedings for previous conferences have been published, some of which are archived on the Web.

10.d. Online Sites

The Early History of Seismometry (to 1900). This is an educational site of the U.S. Geological Survey center compiled by James Dewey and Perry Byerly which describes early seismoscopes, their invention, and development, along with some of the early scientific controversies.
http://gldss7.cr.usgs.gov/neis/seismology/history_seis.html

Rail Inspection. There is a well-illustrated history of magnetic and ultrasonic testing of rail lines in America on the Center for Nondestructive Evaluation site at Iowa State University, contributed by Robin Clark of Sperry Rail Systems. http://www.cnde.iastate.edu/ncce/UT_CC/Sec.6.1/Sec.6.1.html

Ultrasonic History & Science Exhibition. An illustrated history of interesting practical applications for ultrasonics. http://www.tsc.co.jp/~honda-el/exhi_e.html

U.S. National Data Center. The Data Center provides information regarding U.S. monitoring related to the Comprehensive Test Ban Treaty (CTBT). It is a gateway between the U.S. and the International Data Center, providing data related to geophysical disturbances, particularly seismic data from nuclear explosions and other major events. The U.S. NDC is established at the Air Force Technical Applications Center (AFTAP). http://www.tt.aftac.gov/

U.S. Navy Marine Mammal Program and Bibliography. The U.S. Navy has an illustrated description of the use of dolphins and sea lions as members of a 'fleet' for a variety of marine tasks and studies. http://www.spawar.navy.mil/nrad/technology/mammals/

Note: If you don't enjoy typing in Web address (URLs), the links have been set up for your convenience on the author's support site. http://www.abiogenesis.com/surveil

10.e. Media Resources

"Cortland Historical Site." The Sugget House museum in Cortland. This contains personal and invention artifacts of Elmer Sperry, inventor of the gyroscope and of a number of important ultrasound technologies. http://www.cortland.org/

"Earthquakes: Living on the Edge," a *History Channel* program in the 20th Century with Mike Wallace series. Details the history of some of the devastating earthquakes in California, Japan, and Mexico. Geologists, rescue workers, and city planners give their views on disaster preparation and prevention. VHS, 50 minutes. May not be shipped outside the U.S. and Canada.

"Medical Imaging," from the *History Channel* Modern Marvels series, this charts the history, from World War II submarine detectors to current fetal monitors, of ultrasound technology as it is used in medical imaging. VHS, 50 minutes. May not be shipped outside the U.S. and Canada.

11. Glossary

Titles, product names, organizations, and specific military designations are capitalized; common generic and colloquial terms and phrases are not.

acoustic spectroscope	an instrument for measuring acoustic attenuation or velocity as a function of acoustic frequency which aids in studying particle size distribution in situations where the attenuation spectra are already known. In practical applications, this instrument can be used to study mixed samples without having to dilute the samples (paint, blood, shampoo, etc.), as with light-based substance analysis, thus preserving their original form.
active tank	an ultrasonic tank stimulated to produce bubbles in a process called cavitation
blanketing	a limiting phenomenon in which the density of the cloud of bubbles in a cavitation field has reached a point where it doesn't become any denser with the application of additional energy. The intensity at this point is called a *blanketing threshold.*
cavitation	a phenomenon in which vapor bubbles form and collapse when a liquid is subjected to high frequency and/or intensity sound waves. Cavitation is a source of interference in sonar applications, but may actually be of positive benefit in certain infrasound and ultrasound industrial applications.
ECAH theory	a theory of ultrasonic propagation in dilute heterogenous systems
electroacoustics	the science of effects in interrelated electrical and acoustic fields, especially within a medium of charged particles
shear wave	a type of wave that propagates more readily in solids than in liquids
sonolysis	a process of applying acoustic energy to biological cells to disrupt their form and/or function
SVP	sound velocity profile
tone-burst	an acoustic pulse comprised of a number of cycles within a given frequency
transducer	a device to convert energy and project it as acoustic energy