Electromagnetic Surveillance 7

Infrared

1. Introduction

This is the first of three chapters that combine to form *light surveillance* (sometimes called *optical surveillance*). The light spectrum includes infrared, visible, and ultraviolet spectra and is itself a subset of the *electromagnetic spectrum*. Infrared, visible, and ultraviolet devices are covered in Chapters 7, 8, and 10, respectively. Chapter 9, Aerial Surveillance, is based predominantly on the electromagnetic technologies discussed in Chapters 5 to 8.

Living and nonliving bodies in our environment radiate energy. Sometimes we can sense this energy. We have evolved eyes to specially sense the *visible spectrum*. Our skin can sense some frequencies in the *infrared* (IR) spectrum, and although we aren't highly conscious of *ultraviolet* (UV) radiation, our skin will show the effects of too much exposure to UV rays by getting sunburned. We have evolved senses that help us to detect situations that might be useful or harmful to us, in which we can locate food or mates, or in which we might be burned or otherwise injured. For the most part, we are equipped to detect levels or types of energy that have a direct impact on normal day-to-day life.

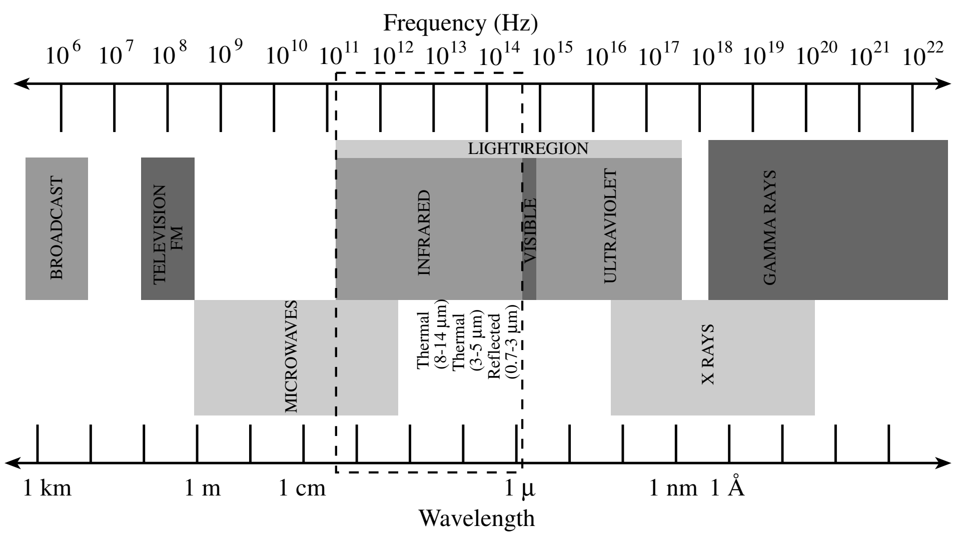
Many types of electromagnetic energy move freely through and around us all the time. Since almost all surveillance technologies depend on some sort of remote-sensing system,

Infrared images like this 1945 photo of a Japanese plane wreck near Mt. Aryat not only aid in various types of surveillance activities, but often have a haunting aesthetic appeal. Note the high contrast of the sky that is characteristic of infrared photos. [U.S. DoD historical photo by Harry Young, released.]

they make use of this electromagnetic energy. Some of this energy can be seen and heard, some of it can be felt, but much of it is 'invisible' to us and travels through our atmosphere, our walls, and our bodies, unperceived by our biological senses. This energy is ever-present and consistent in many respects, and thus can be harnessed and used in terms of its information-carrying capacity, even if we can't sense it directly. It is often converted from one form of energy to another in the course of its use.

Optical Technologies

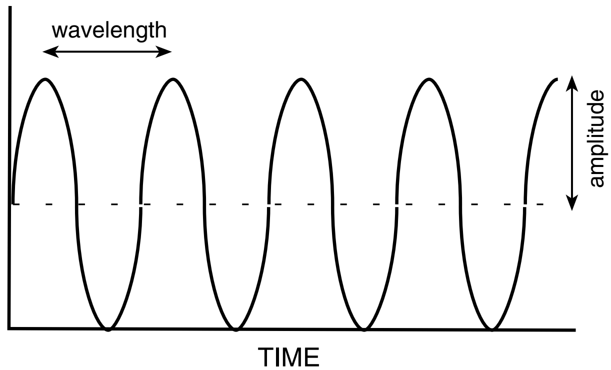
Light-based phenomena can be manipulated with lenses and mirrors to create surveillance devices. Thus, most telescopes and cameras fall within the category of *optical technologies*. Devices that sense light are called *photodetectors*. Light includes energy that we can see (e.g., the colors of visible light) and energy that we can't see, including the *ultraviolet, visible,* and *infrared* spectra, extending from about 0.01 µm to about 1000 µm). These forms of radiant energy have both particle and wavelike properties. Chapters 7, 8, and 10 together provide related information on different forms of light.



Infrared radiation is a region of longer wavelengths next to the visible spectrum and somewhat overlapping radio waves (microwaves). It has been further subdivided into near-, middle- and far-infrared regions, though these 'boundaries' vary, depending on the application.

Representing Waves

Wavelengths are symbolically represented in two-dimensional diagrams as *sinusoidal curves.* One wavelength or repetition is called a *cycle*, or the distance from a point on a peak (or trough) to the corresponding point where the next cycle begins. Infrared wavelengths near the visible spectrum have shorter wavelengths, gradually getting longer as the frequency decreases toward the microwaves. There are no hard and fast boundaries, visible light transitions into infrared at the point where people no longer can see it, which varies from person to person, and infrared overlaps with the region of radio waves called *microwaves* because the distinctions are sometimes based on technology used to harness the energy, rather than changes in the phenomena themselves.



Wavelengths of radiant energy are often represented as repeating sinusoidal curves, with one wavelength being one cycle. Another way of representing a cycle is to imagine a second hand on an analog clock spinning around and around, with each new cycle starting when the hand passes 12. Since each new cycle would be overlaid on the previous cycle and would be hard to visually distinguish from the previous cycles, we usually 'stretch out' this graph so that each cycle appears as mountains and valleys rather than as continuous circles. Either way, the idea is to graphically represent repeating events of similar character.

Loss of Radiant Energy

Attenuation is a reduction or *diminution* of a signal from a variety of causes. Imagine a flashlight shining out into the dark. The light gets gradually dimmer as you move out farther from the source until it no longer illuminates the objects around it due to the light being either scattered by reflective objects or absorbed by absorbent objects (which are usually dark or porous). Infrared thus gets 'dimmer' or weaker as it moves out from the source.

Scatter and *absorption* are important concepts associated with attenuation. Scatter occurs when the radiation is reflected in a number of directions in such a way that there isn't sufficient 'signal' left to trigger a sensing device. Materials like *chaff*, strings of reflective material that deliberately scatter radar signals, are often used in countermeasures systems. Absorption occurs when the infrared radiation is absorbed by some object and rather than being reflected or re-emitted at the same wavelength, it may be re-emitted at some other wavelength that may not be in the range of the detector.

Units of Measure

Outside the light spectrum, the differences in the lengths of waves between very short waves in the *gamma-ray region* and very long waves in the *radio wave broadcast region* are huge, so huge they challenge the imagination. Because of these great differences, wavelengths are expressed in terms of their length in whatever units are easiest to handle mathematically and conceptually. In other words, different units are used for different parts of the spectrum.

Imagine trying to describe something very small, like a flu virus or bacterium. It isn't very practical to use feet or meters to describe microscopic sizes. Instead we use tiny units like *microns*. Now imagine trying to describe the circumference of the Earth or the distance to the Moon. A measurement in microns is possible, but unwieldy and impractical; instead we use miles or kilometers. When describing wavelengths in the optical spectrum, we typically use *microns* or *micrometers* (e.g., 3 µ or 3 µm) or *nanometers*, which are 1,000 microns each (e.g., 3000 nm), and sometimes ångstroms (Å), which are described in the Ultraviolet chapter.

Infrared Radiation

Infrared is considered to be at the 'lower energy' end of the optical spectrum and the wavelengths associated with infrared are longer than those associated with the visible and ultraviolet regions. Some sensing devices that operate in the optical frequencies are *broadband* devices, in other words they not only detect infrared, but also visible and ultraviolet frequencies.

Infrared is invisible to human eyes, but it is not completely 'invisible' to human senses. We can feel heat from a fire without touching the flames, even with our eyes closed, because our nervous system is designed to sense infrared radiation in certain *thermal* energy regions that might do us harm. However, this sensitivity is not as specific or as well-developed as our sight and hearing. In contrast to humans, some animals have very well-developed infrared sensors. These aid them in locating prey or hosts, especially in low light. Several varieties of snakes have an organ in a 'pit' on each side of the head, between the nostrils and the eyes, which senses infrared to a few feet. The distance between the pits, like the distance between the eyes, aids the creature in locating the source of the radiation. These sensors may also help snakes to find 'warm spots' in which to sunbathe, since they are cold-blooded reptiles and must seek heat from external sources. Snakes are not the only creatures with heightened infrared sensitivity; some parasitic creatures, like the bee-mite, appear to have infrared sensors to help them locate hosts.

Infrared radiation can be generated in many ways, through electrical activity, biochemical reactions, combustion, and nuclear interactions that are natural or manmade. Infrared comprises about half the radiation emitted by the Sun and is the primary radiation from many types of bodies. Directed infrared beams can be generated by lasers. Natural and synthetic infrared sensors allow us to detect, measure, and record this type of radiation, which is then usually converted to electrical signals for processing and viewing. Within the infrared region, there are further categorical distinctions which will be discussed in the following sections.

Infrared radiation is all around us. Unlike radio waves, which are mostly synthetic, infrared is emitted or reflected by all bodies within our solar system. This makes it both a useful and a challenging technology. Infrared is useful because it is almost everywhere. We don't have to look hard to find it. But, infrared is challenging for the same reason: because it is almost everywhere. Too much of it makes it harder to distinguish the relevant and useful information from all the other radiated infrared that is likely to be detected at the same time. Locating the information we want from an infrared scan can be like locating a friend in a crowded sports stadium. More than any other surveillance technology, infrared is context-sensitive, so Section 3 (Context) is more extensive in this chapter than in others. This will help the reader understand that human problem-solving strategies are often an essential aspect of infrared detection and interpretation.

Despite the technical challenges, infrared devices are widely used in reconnaissance, navigation, imaging, astronomy, security systems, and the remote-control devices that are associated with surveillance technologies like camcorders, VCRs, etc.

Infrared devices are particularly good at detecting 'hot' objects (electrical circuits, fires, people crossing borders in the dark, etc.) and for 'seeing' in the dark, or through visual impediments such as haze. In this case 'hot' is a relative term, describing the relationship of the object being investigated to its background. To appear 'hot,' the object may need a supplemental source of infrared illumination.

Infrared can be detected by a simple thermometer, or by more sophisticated instruments such as the *thermopile, bolometer* and, more recently, *pyroelectric* devices, described in more detail later. While some photodetectors are sensitive to radiation in the ultraviolet or visible spectrums, most of them operate in the infrared wavelengths.

This chapter will describe a wide range of applications using infrared technologies and explain why the use of infrared is closely linked to the type of problem being solved, and the types of equipment that are needed to solve certain classes of problems. From a surveillance point of view, it covers a lot of interesting technologies:

- night vision scopes and sensing devices
- remote-control and communications systems
- infrared films and cameras
- security systems, especially motion detectors and fire detectors
- aerial reconnaissance and imaging systems
- inspection, quality control, and chemical composition sensors

As can be seen from this list, infrared sensing is a versatile technology that is used in many different types of devices, many of which are used for security and are priced in the consumer range.

2. Types/Variations

Compared to visible light, infrared is quite a broad region of the spectrum. Since it borders visible light at the shorter wavelengths, it has some characteristics in common with visible light and since the longer wavelength region of infrared borders and even overlaps with radio waves, it has some characteristics in common with radio waves. There are even some subregions or windows within infrared that are suitable for particular purposes. Thus infrared is a varied, versatile, and complex region of the electromagnetic spectrum.

2.a. Infrared Categorizations

Units

To understand how the infrared spectrum is divided into subcategories, it helps to understand the units that are used to express infrared wavelengths and the relationship of a wavelength to other measures.

As has been mentioned elsewhere, *wavelength* and *frequency* are mathematically related. If you know one value, you can calculate the other, since the value for the speed of light stays constant (assume light is traveling unimpeded through a vacuum). Thus, the speed of light divided by the wavelength equals the frequency ($c/\lambda = f$) and, conversely, the speed of light divided by the frequency equals the wavelength ($c/f = \lambda$). This relationship is useful not just for calculations related to the different forms of light (infrared, visible, and ultraviolet), but for other electromagnetic radiant energies as well.

Since we have a convenient relationship between wavelength and frequency, one of the most general and common ways to break up infrared is to divide it logically or mathematically into subregions based on wavelength (from which the frequencies can be calculated as needed). Since infrared wavelengths are short, shorter even than most radio microwaves, they are expressed in small units. The length of the wave is usually expressed in units called micrometers or µm. These are sometimes referred to as *microns* or simply symbolized with µ. A micron is 1/1,000,00 of a meter or 1/1,000 of a centimeter. Knowing this will help you interpret the chart on the following page, which shows three different schemes for subdividing the infrared spectrum.

Some categories are based on regions or *windows* that are known to be useful for observation and measurement (usually those which are less subject to attenuation or which have good target-background contrast ratios), still others are specified in terms of their associated detection and imaging technologies or as 'generations' of evolutionary improvement.

Infrared Categories Based on Wave's Length with Sample Applications

Designation	Abbr.	Waveleng.	Sample Applications
short-wavelength infrared	SWIR	1 - 3 µm	astronomy and laser applications
medium-wavelength infrared	MWIR	~3 - 5 µm	(higher atmospheric transmission) - higher contrast, better in clear weather; space remote sensing
long-wavelength infrared	LWIR	~8 - 14 µm	(higher atmospheric transmission) - less background interference, better in weather with particles (fog, dust, etc.), military, industrial applications

Infrared Categories Based on 'Distance' from Visible Light with Sample Applications

Designation	Abbr.	Wavelength	Sample Applications
near-infrared	NIR	0.7 - 0.9 µm	Adjacent to the visible spectrum, the commonly used range for photographic sensing and vidicon cameras. Most thermal energy emitted from objects up to the temperature of the Sun are in this portion. 'Hot' targets can be readily detected. Primarily photographic, photoemissive devices. Devices can be used in daylight or dark, but in dark will only detect hotter targets without supplemental illumination. Used in night-detection, photography, meteorology, and navigation.
middle-infrared	MIR	0.9 - 20 µm	Includes the peak radiation from fires and much of the energy reflected off objects illuminated by the Sun (hence, may not work as well in very sunny regions). Primarily photoconductors, photodetectors. Used in medical diagnostics, electrical and other construction inspection and quality control, locating hot objects obscured by smoke.
far-infrared	FIR	20 - 1,000 µm	Includes the temperatures which are cooler. Useful for high-resolution applications, line scanners, forward-looking infrared (FLIR), and other systems intended to function in light rain, smoke, etc. at normal temperatures. Used in surveillance, mapping, fire detection, and medical diagnosis.

Two General Categories of Infrared Radiation

Designation	Abbr.	Waveleng.	Description
reflected infrared	—	0.7 - 3 µm	Within this range, 2.5 µm is approximately the upper limit for reflected solar energy for remote sensing.
thermal infrared	—	3 - 5 µm	About 6 µm is the lower limit for self-emitted thermal energy [Lo, 1986].
thermal infrared	—	8 - 14 µm	Within this 'window' is a region (about 9.7 µm) which is the dominant wavelength of the Earth [Lo, 1986]. This is more easily detected on the dark side of the Earth where there is less interference to the infrared emissions from the Sun's rays.

Categories

Many of the classification schemes for infrared are not mutually exclusive but rather are ways of focusing on relevant factors which may overlap. Some classification systems are based on the character of the emissions. Are they solid or gaseous? Solid emissions exhibit a continuous distribution of energy, whereas gaseous emissions have 'boundaries,' that is, discrete spectral lines. These spectral lines can be extremely useful in identifying the composition of the substances which are emitting them. Note that *thermal* radiation is not a separate phenomenon from infrared, but rather a way of describing certain properties or regions of infrared light.

Technological considerations, problem-solving strategies, and categorizations are discussed further in the following section (Context). It is important to remember throughout these discussions that there are rarely sharp dividing lines between categories in analog systems, that many categorical divisions are approximate, and that charts that divide middle-infrared from far-infrared, for example, indicate areas of transition rather than distinct 'walls' that separate one type of energy from another.

As can be seen in the preceding charts, the infrared region has been divided in various ways, based on the length of the waves and/or on technologically useful 'windows' (wavelengths that respond well to particular types of detectors, or which are less prone to noise from atmosphere or other confounding background radiation). Since the Earth's atmosphere reduces the contrast between the target and the background (increasing the *target-clutter* or *signal-to-noise* ratios), compensatory technologies are often used in conjunction with the raw data to try to improve the signal. At the current level of technology, the near- and middle-infrared regions have sufficiently high energy levels and reflective and emissive properties to be useful for many applications.

Near-infrared has many properties in common with the visible spectrum, such as the ability to influence film, and is particularly useful for film imaging systems.

Far-infrared regions are less useful in a general sense due in part to their low reflectivity and interference by ambient temperatures. However, far-infrared still has emissive characteristics that may be important in situations where the target and background characteristics are sufficiently different or where their spatial characteristics are known and can be compared with other data (such as medical imaging and fire detection).*

In general, *near- or middle-infrared* spectra exhibit vibrational motions while *far-infrared* or *microwave radiation* produce rotational motions (e.g., as in gas molecules). Distinct and consistent spectral lines can be detected in some substances (e.g., sulphur) and these characteristics are useful for identification and quality control using infrared devices. As the density of the substance increases, interactions at the atomic/molecular level tend to increase the level of continuity in the spectrum. Substances with temperatures above 0 Kelvin display molecular motion and hence can directly emit heat, i.e., thermal radiation [Holz, Ed., 1973].

Because so much of infrared technology depends on target-background distinctions, systems have been developed to express these quantities. Thus, *target contrast* is usually expressed in terms of ratios (e.g., 4:1) or degrees (20°). Since the information derived from infrared sensing is not always sufficient or sufficiently detailed, multispectral systems that

*Because technology is always evolving, no part of the spectrum can be discounted as permanently worthless. Some radio frequencies that were once considered unusable are now the backbone of important communications systems. In a similar way, infrared frequencies that are hard to use at the present time, might become extremely useful as a result of future discoveries.

allow the study or imaging of the same data from the point of view of different wavelengths or devices are often used in conjunction with one another to provide a composite picture.

Devices which synthetically generate infrared radiation tend to be of two types:

cavity radiators - These are designed to emit, as closely as possible, *black body* radiation (a theoretical body that absorbs all incident radiation). There is no perfect human-made black body, so it is mainly used as a theoretical construct.

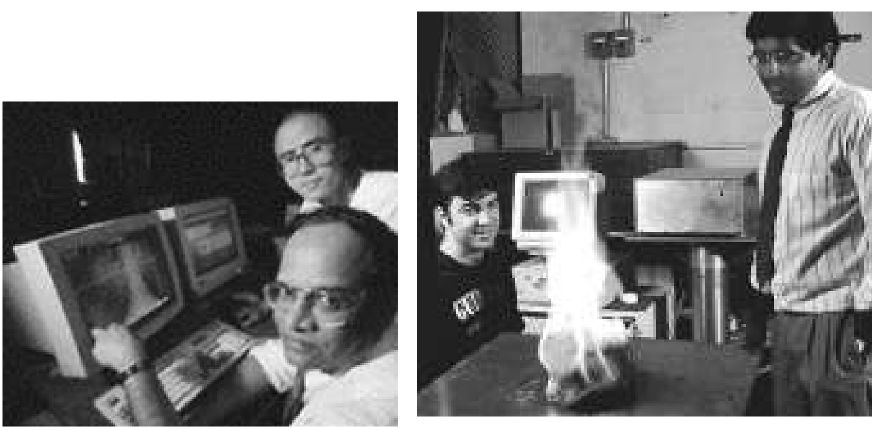
solid radiators - This includes any radiators which are not black body radiators.

2.b. Types of Detectors

Passive and Active Detectors

Passive detectors are those which sense radiant energy in the infrared region without supplemental illumination. Thermometers, the human skin and nervous system, and snake infrared sensing 'pits' are examples of synthetic and natural *passive infrared-sensing systems*. In contrast, *active detectors* require a source of illumination to detect a target. Infrared-sensitive night-vision goggles require supplementary illumination as do infrared cameras when photographing in low-light conditions.

Infrared sensors have been used to develop many different types of fire alarms. Traditional smoke detectors are only activated if smoke particles reach the detector, but scientists are working on infrared detectors that can respond to radiation in the infrared frequency, even if there's not enough smoke to reach the detector.



Purdue University, professor Jay Gore (left foreground) and research scientist Yudaya Sivathanu (right standing) have developed a sensitive detector that responds to near-infrared radiation, which may reach the detector directly or by being reflected off various surfaces. In other words, it can sound an alarm even if the smoke particles don't reach the detector. The system detects characteristics such as fluctuating frequencies that are specific to an uncontrolled flame, in order to avoid false alarms from a hotplate, for example. This innovative device incorporates fiber-optic technology so it can be linked through a cable distribution system to a central detection unit. A computer at the Purdue lab has been programmed to repeat safety instructions to people in the vicinity of an alarm. The computer terminals are used to investigate air flow into a fire and fire emissions which may eventually influence building ventilation codes and aid firefighters in evaluating the presence of toxic gases. Gore's previous research includes helping NIST researchers to analyze oil well fires in Kuwait. [Purdue 1997 news photo, released.]

Thermal and Photon Detectors

Most photodetectors can be classified into two main categories:

thermal detectors - These are manufactured with temperature-sensitive materials designed to absorb incident radiation through a broad and uniform spectral sensitivity. Through thermal excitation, the kinetic energy of electrons in the higher velocity ranges is converted to potential energy which is then used to register the presence of excitation or the level of excitation. Examples of thermal detectors include Golay cells, thermocouples, bolometers.

pohoton detectors - These are typically semiconductor detectors in which excitation of absorbed photons causes the electrons to move into a *conduction band*. This response to incident radiation by electron excitation is usually expressed in the form of an electrical response that can be displayed according to its characteristics. Depending on how the response is observed, photon detectors can be

- *photoemissive* - electrons are emitted into the surrounding medium
- *solid state* - photons influence energy distribution within the material

The near-infrared region is particularly important as it encompasses most of the thermal energy emitted from objects with ambient temperatures up to 6000K, which is the surface temperature of our Sun.

Thermal and Pyroelectric Detectors

When bodies absorb infrared energy, there is an associated rise in temperature. *Thermal detectors* are designed to detect the resulting radiated 'heat.' Since thermal detection is based on temperature changes rather than on sensitivity to a particular wavelength, it is a broad-spectrum technology that senses not only infrared, but also visible light and ultraviolet. Bolometers based on thermal sensing are used in altimeters, satellite Earth-monitoring systems, and non-contact thermometers. Traditionally, many of these types of devices were ceramic-based, but they are being superseded by semiconductor devices for a wider range of applications. Semiconductor detectors are associated with lower costs, a wider range of operating temperatures, and greater resilience to large-incidence optical power (e.g., pulsed lasers).

Thermopiles are thermal detectors which generate voltages when exposed to heat and thus are good for measuring sources of continuous-wave or repetitively pulled radiation. They are slower to respond than pyroelectric sensors.

Pyroelectric detectors are a more recent type of thermal detector and are more sensitive than traditional bolometers and thermophiles. They respond to temperature differences rather than generating a voltage and respond more quickly than traditional thermopiles. Pyroelectric detectors are also broadband detectors, sensitive from far-infrared to ultraviolet. By varying the absorbing surfaces of the detector, devices with different sensitivities can be designed. Chromium and specialized black paint are two substances that can be used as absorbing surfaces.

Extrinsic and Intrinsic Detectors

Intrinsic detectors usually operate at higher temperatures than extrinsic devices. They have higher quantum efficiencies and dissipate less power. One example is the quantum-well infrared photodetector (QWIP). Extrinsic detectors include the InGaAs/InP direct-bandgap intrinsic detector.

Advanced Generation Systems

Infrared devices are further distinguished by their evolutionary improvements. *Second-generation* infrared-sensing systems can detect and identify targets at significantly greater distances than their predecessors. Second-generation performance is provided in a number of ways, including specialized closed-cycle cooling systems and improved detector arrays. A Standard Advanced Dewar Assembly (SADA) is an advanced type of detector module.

Scanning and Staring Arrays

Two important classifications of infrared devices, particularly those used for imaging, are *scanning* and *staring*. These are used in conjunction with *infrared detector arrays*, that is, a series of small detectors mounted in such a way that their individual inputs can be integrated to form an image. The distinction isn't based on wavelengths or heat-sensing properties, but rather on how the image is built up. This simple example helps explain the difference between the two basic approaches:

scanning - Imagine viewing a scene through a narrow tube. You can only see a little bit at a time, so you have to move the tube around to take in the various details of the scene. Despite the limited field of view, after a few movements you can build up a pretty good image of the scene in your mind. Scanning systems are similar to this. A mechanism scans the scene past a detector array to build up a composite image of the scene. Just as your brain forms a 'picture' of the scene, a video display or photographic system can be designed to display a composite picture of an infrared scene. Scanning technologies are commonly used in tactical systems.

staring - Now imagine removing the narrow tube and just 'taking in' a scene all at once, the way you normally see. Staring systems are similar to this. The detector array 'stares' at the whole scene for a period of time designed to be sufficient for each detector to take in a part of the image and have it integrated and transmitted to an associated processing system. CCD cameras operate on this general principle. Systems that register the scene quickly, so that the next scene can be imaged in time to record motion, are particularly useful. Staring systems are often used for tracking and imaging.

Cooled and Uncooled Detectors

Infrared radiation is sensed in a wide range of operating temperatures, from -269°C (4K) to 40°C (313K).

While there are many types of room temperature infrared detectors, smaller, more sensitive electronics often have smaller bandgaps for detecting lower energy photons. Since the surrounding heat can influence the operation of the components, they may be cooled to control the thermal excitation. In simpler terms, cooling an infrared device helps keep the radiation associated with the device from interfering with the radiation you are trying to measure. Liquid nitrogen and liquid helium are two elements commonly used to cool infrared devices.

Substances sensitive to infrared which are commonly used in cooled infrared devices include

- lead sulphide (PbS) - above approx. 3000 cm^{-1}
- indium antimonide (InSb) - above 1400 cm^{-1}
- mercury cadmium telluride (MCT) - above approx. 700 cm^{-1}

Certain substances will impede or block infrared, such as glass or water, and are not suitable for lenses designed to be transparent to infrared. If glass impedes infrared radiation, then how is it possible to use a regular camera for infrared photography? It's because wavelengths in the near-infrared, adjacent to the visible spectrum, can pass through glass more readily than longer infrared wavelengths. This is one of the reasons that consumer infrared-film photography only records a short distance into the infrared spectrum. Longer wavelengths can, however, be imaged with specialized systems and lens materials other than glass, ones that allow the infrared to pass through.

Precious and semiprecious gemstones are used in many illumination and detection technologies, especially lasers (ruby, garnet). Illumination through sapphire, which is transparent for visible and infrared radiation to beyond 5.5 µm or even farther, can be achieved by thinning the sapphire.

Most infrared sensing is accomplished with nonfiber technologies at analog transmission rates. Typically, the wavelength (λ) and its amplitude are detected. In digital applications, the wavelength and the pulse amplitude are relatively fixed and so do not provide information that is as useful. Instead, the existence of a pulse and the pulse rate are sensed, with the amplitude being largely irrelevant [Bass, Ed., 1995].

In spectroscopy, in which the unique spectral properties of substances are studied, both the wavelength and strength of a signal are used for detection and identification.

3. Context

Context is an extremely important aspect of infrared detection and imaging. Infrared radiation is found in varying quantities throughout our world and it can often be difficult to interpret data or pinpoint the specific source of infrared radiation. When infrared is used as a detection or tracking technology in automated systems, it is often backed up with evaluations and judgment by individuals or operations teams and combined with data from other surveillance technologies.

Ambient Radiation

As mentioned earlier, infrared is one portion of the *optical region*. Our world is full of animate and inanimate objects radiating energy in these wavelengths. About half the energy that radiates from the Sun is in the infrared range [Holz, Ed., 1973]. Our own bodies are constantly radiating infrared energy in the form of heat. Most of the infrared in our environment is generated naturally, though it is possible to generate infrared radiation with illuminators and lasers. This is in contrast to radar, where there is little natural radiation in the radar range of frequencies, and most of it is synthetically generated.

Some forms of infrared radiation are easy to detect and there are many consumer-priced infrared devices that take advantage of infrared wavelengths that are prevalent or easily distinguished (security systems, remote controls, camera autofocus (AF) systems, infrared films and lenses, night-vision scopes with illuminators). Other aspects of infrared are technologically challenging to construct or interpret, including supercooled devices and various computerized imaging systems which can be relatively sophisticated and expensive (such as aerial remote-sensing systems and astronomical telescopes).

In infrared detection, as in radar, the object that is being sought or sensed is called the *target*. The context or environment associated with an infrared target is called the *background* and objects or particles that get in the way and tend to scatter the radiation are collectively called *clutter*. Longer infrared wavelengths can move through particles in the atmosphere more readily than visible light and thus are useful for seeing through fog, dust, and other particulate matter that usually clutters the view.

Common Applications

Common infrared targets include people (customers, intruders), wildlife (game, injured livestock, research animals, insects, birds that migrate at night), astronomical bodies, electrical faults, fires, drug-growing operations, underground or building piping systems (especially heat ducts or hot water pipes), circuit boards, buildings (roofs, walls), and fires (arson, house fires, forest fires). As a rule of thumb, if it emits heat, or contrasts in temperature in comparison to its environment, it's a good candidate for thermal infrared detection. Some targets and detectors require supplemental illumination to be visible in the infrared range.

Infrared film is readily available for standard and special-purpose cameras. Most infrared film is sensitive to visible and near-infrared reflected light and so cannot be effective in the dark unless a source of illumination is provided (the 'light' will not be seen by human eyes, but will reflect off objects and back to the camera to expose the film). The presence of bright sunlight will intensify photographic effects. Heat sources that are mostly reflecting in the far-infrared (about 10 to 100 μm) do not show up on infrared film, but can be seen with other types of viewing and recording systems which often need to be cooled in order not to interfere with the incoming radiation.

Interpretation of Infrared Data

There are two interrelated aspects of infrared sensing that pose special challenges:

- detection of targets that are fast-moving, or which produce small (infrequent or quick-burst) or weak (lower energy-level, far-infrared) signals
- image processing/interpretation in circumstances where the target doesn't contrast strongly with the background or in which there are infrared-opaque particles obscuring the image

The second point is the one that brings human problem-solving skills into play. The human brain is still one of the most important 'components' of most infrared-sensing systems. Just as well-trained radar operators (e.g., air traffic controllers) become experienced in the interpretation of radar scope images, infrared detection and imaging systems are dependent on the ability of the user to apply good problem-solving strategies and procedures to the information received.

The problem of finding-a-small-target-in-a-crowd characterizes a large part of infrared technology. Scientists have to solve difficult *target-clutter* and *signal-to-noise* problems due to the ubiquitous nature of infrared radiation. That is not to say that all infrared imaging problems are this challenging. If your friend is standing alone or with one or two people in a grove of trees in the dark, infrared night-vision products may help you locate his position, or at least the position of the small group of people. Infrared products are particularly useful for this type of situation where the target is clearly distinguishable from the background, and where the characteristics of the target (such as arms and legs and walking movement) make it clear that it is a person.

Since the world is full of infrared radiation, the goal of infrared detection is to locate 'useful' information, that is, radiation that contrasts or distinguishes the desired target, or which appears different over time. Since the atmosphere and surrounding terrain emit infrared radiation that may interfere with detection (unless you are specifically sensing the atmosphere or terrain itself), there are wavelength 'windows' that are more useful than others for distinguishing a target from this background clutter.

Objects glow most noticeably in the 8 to 10 μm range, and cameras and detectors that sense within this range are useful for surveillance, security systems, and navigation systems.

Thermal maps of biological organisms taken in this range are useful for biological research and medical imaging. The absorption lines of gas molecules also lie in the long-range infrared region, making it useful for atmospheric studies and monitoring.

Displaying Infrared Images

Infrared photography is a useful surveillance technology because it can be used in daylight to reveal details that do not show up on normal film ('normal' in that the colors/values approximate those consistent with the human visual system). At night it can record details invisible to human eyes. To take infrared photos at night, a high-intensity infrared light can be used for illumination. This will normally not be seen by others in the vicinity, but allows more information to be captured on film (or with a digital camera) than can be captured with visible-light systems.

Each region of infrared has its limitations for being captured on film or video. Below wavelengths of 1 µm, silicon-based CCDs (those used in video cameras) are rapidly superseding photographic plate systems for imaging infrared. For slightly longer wavelengths, from about 1 to 3 µm, the silicon-based CCDs are not quite as effective, as they decrease in quantum efficiency due to what electronics engineers call a *solid-state bandgap*. Other materials have been tested for use with longer wavelengths with the tradeoff that they are somewhat lower in resolution than the silicon imaging arrays.

Materials used to detect infrared are constantly under study and change when higher precision or less expensive options are found.*

As can be seen from this discussion, infrared sensing and imaging really represent a wide range of technologies and cut through hundreds of fields of study and application, more specific examples of which will be provided later.

4. Origins and Evolution

Most of our scientific understanding of infrared is recent, as its existence and properties were discovered less than 250 years ago. The more sophisticated devices for imaging infrared have only become common in the last few decades.

The Discovery of New Forms of Light

The discovery of the infrared region of the optical spectrum is attributed to a German-born musician/astronomer, Friedrich Wilhelm (William) Herschel (1738-1822). Herschel immigrated to England in 1757 where he became a music instructor who took time to systematically explored the sky as an amateur astronomer. In 1800, Herschel made a simple but significant observation. He reported that while using a glass mercury thermometer to measure temperatures in different regions of the visible spectrum, he noticed a change in temperature that continued past the portion perceived as the color red, suggesting the existence of wavelengths beyond those which he could see.

Herschel's discovery led to scientific debates about whether the newly discovered radiation was a type of light or a phenomenon that was different from light. The observations of Leslie in 1804 showed that different materials had quite different radiating and absorbing qualities, thus suggesting light and heat might be distinct phenomena. Herschel himself thought that the newly discovered radiant energy might be separate from visible light. Further experiments by his son led to the conclusion that the radiation that was invisible to humans was

*In the near-infrared ranges from about 1 to 5 µm, InSB and HgCdTe are common. As the wavelength increases, we find Si:As BIB, Si:Sb, and Ge:Ga being used.

similar to visible radiation and differed not so much in character as in momentum. This radiation is now known as *infrared*, to describe it as being 'below' the red region of the visible spectrum, in other words, at lower frequency levels than the color we perceive as red.

New Devices That Led to Further Discoveries

The 1800s was a time when many great minds were trying to understand physical phenomena such as light, electricity, and magnetism. At the same time, inventors were creating devices to harness their capabilities. While studying electricity and magnetism, Hans Christian Ørsted (1777-1851), a Danish scientist, and Jean B. J. Fourier (1768-1830), a French mathematician, invented the first *thermoelectric batteries*, around 1823, by welding pairs of antimony and bismuth welded in series.

The development of the *thermopile* (an electric thermometer) by Italian inventor Leopoldo Nobili (1784-1835), in 1829, provided a better means to detect infrared than a conventional thermometer. Bolometers were developed a number of years later and further improved by Macedonio Melloni (1798-1854), who collaborated on some projects with Nobili. Melloni developed a thermomultiplier which consisted of a cone aimed at the heat source with an astatic galvanometer connected to the terminals of the thermomultiplier. Compared to a thermometer, Melloni's thermomultiplier was fast and sensitive. With low-intensity radiation, there was proportionality between the angular deflection of the galvanometer needle and the temperature difference between the opposite batteries. For more intense radiation, the proportion was more complex; a lookup table was often provided with the device, which listed intensity in terms of degrees.

By the 1830s, studies by Thomas Seebeck with more sensitive equipment than had been available to Herschel, revealed some of the characteristics of infrared radiation, but it was not until almost 50 years after its initial discovery that it was accepted that the nature of infrared was consistent with that of visible light. In the 1870s, James Clerk-Maxwell (1831-1879) contributed some important theories about electromagnetic radiation and a series of mathematical equations which would be used to resolve theoretical and mathematical inconsistencies. Josef Stefan (1835-1893) and Ludwig Boltzmann (1844-1906) also provided important tools for modeling the characteristics and behavior of infrared radiation. The Stefan-Boltzmann Law was a theory of black body radiation first demonstrated by Stefan that was later described mathematically by Boltzmann, in 1884. Stefan was also known for research in heat conduction and kinetic theories related to heat.

In 1905, W. W. Coblentz published a classic reference book on the infrared spectra of organic and inorganic compounds, including not just solids, but gases and liquids, as well. This remarkable book, called *Investigation of Infrared Spectra*, still provides the basic information that aids in understanding spectra and their practical applications in spectroscopy.

The Emergence of Practical Applications and Accessories

By the 1930s, infrared science and technology had improved to the point where practical commercial and industrial applications could be developed. Spectrometers were improved and devices to automatically detect and/or record infrared were developed.

In 1932, Mr. Bloch at Ilford, a company known for its photographic products, developed faster emulsions on glass plates that were suitable for use in aerial photography. A deep red filter was used, instead of yellow.

In 1933, two British open-cockpit biplanes were equipped so they could survey closed Nepalese territory using infrared photos taken in the vicinity of the Himalayas. The camera was mounted in slings under the plane, at an angle, with leather pouches as shock absorbers.

(Details of this hair-raising pioneer mission are included in the chapter on Aerial Surveillance.)

Many of the significant production advancements in infrared technologies occurred during World War II, when research dollars were directed toward the improvement of surveillance devices and infrared was of interest because it allowed field personnel to find hidden installations and to see in low light conditions. At the end of the War, improvements in the technology were incorporated into commercial systems, including faster sensors and automatic recording features.

In 1947, Kenneth Neame of the Royal Air Force took photographs in an unauthorized flight over Mt. Everest in a Spitfire XIX. Nepal was still a closed territory and had not been fully explored or mapped by westerners. What little was known about the region from the ground was determined by spies using age-old, low-tech surveillance techniques, i.e., they disguised themselves as holy men [Greer, 1994].

High Altitude Surveillance

In the 1950s, rocket science took off and scientists were quick to mount cameras on the airborne projectiles to record the world from new perspectives. Originally the cameras were used for recording the orientation of the rockets, but later they were also used for observation. Rockets weren't ideal as surveillance craft, as they shook, were subjected to high heat, and were only airborne for a few minutes, but they eventually became important for launching other types of technologies into space or into the upper atmosphere.

In the 1960s, improvements in aircraft and the deployment of orbiting satellites led to new applications and developments in remote sensing using infrared detectors and recording media. The interpretation of infrared data also improved. Multispectral scanners were installed in aircraft [Curran, 1985].

In the late 1960s, there was a lot of interest and research into mosaic focal planes, both non-planar and planar. However, a decade later, they were still somewhat lacking in commercial utility.

This is a Grumman OV-1C aircraft, called the Mohawk, which came into production in 1959 as a reconnaissance and photo-observation craft for the U.S. Marines and the U.S. Army. The "C" designation indicates that the aircraft was equipped with an infrared electronic reconnaissance imaging system. [NASA/Dryden Flight Research Center 1983 news photo, released.]

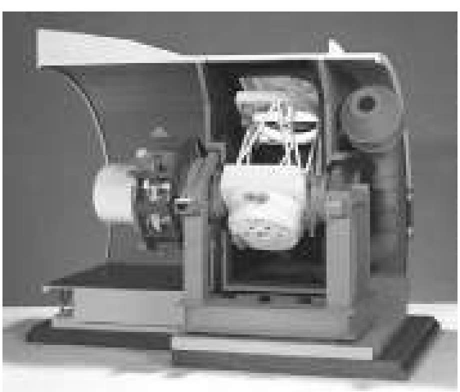
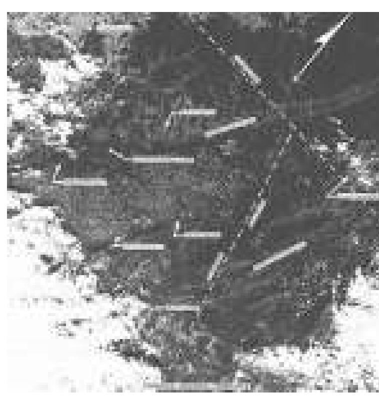
Infrared Photography and Imaging

The recording of infrared images on photographic film was influenced by developments in the photographic industry in general. In the 1960s there was widespread use of black and white film and experimentation with different emulsions and development processes. Infrared photography was being used in many contexts by the late 1960s. As color films began to emerge and drop in price, color infrared film became available, filters were developed (for both color and black and white films), and false-color interpretation techniques were being developed.

The 1970s - Commerce, Computers, and Science

Advances in technology, computerization, and miniaturization caused infrared technologies to proliferate in civilian applications in the 1970s. It became more broadly applied in atmospheric, oceanic, and agricultural studies (e.g., speculation related to world cereal production). Microcomputer-based interpretation software and display devices contributed to infrared imaging technology. Improvements occurred in computer memory capacity, especially dynamic RAM. Image display size and resolution improved as well.

Silicon chip technologies emerging in the 1970s made it possible to develop charge-transfer devices (CTDs) that could be used for infrared detector readouts. First-generation photoconductive HgCdTe (Mercury-Cadmium-Tellurium) arrays used in infrared sensing began to be available in high volume in the 1970s. HgCdTe and InSb (Indium-Silicon) are semiconductor infrared sensing materials that can be used in conjunction with a signal-processing, silicon-substrate chip to create hybrid arrays that can provide larger numbers of detectors and higher resolution. Monolithic arrays also continued to evolve.

Left: This is a model for an infrared telescope intended for airborne use with the Kuiper Airborne Observatory. Right: An infrared image of the Alabama State region taken from Skylab's Earth Resources Experiment Package (EREP) using visible-light and near-infrared photography, infrared spectrography, and other sensing technologies (with labels superimposed afterward). [NASA/Ames Research Center 1972 news photo by Geaton Farrone; NASA/Marshall 1973 news photo, released.]

The first comprehensive global inventory to use the new imaging technologies took place in the mid-seventies. Infrared remote-sensing was used for surveilling crops in the U.S.S.R., China, Latin America, and India. In the Large Area Crop Inventory Experiment (LACIE), Landsat sensor data were analyzed and used to calculate wheat production. LACIE was replaced in 1980 by AgRISTARS (Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing) [Curran, 1985].

The transition from analog to digital systems was gradual. Mosaic focal plane arrays, developed in the late 1970s, comprised part of the transition. However, they still had limitations such as uniformity and dynamic range, so there was a strong interest in improving the sensitivity and resolution of detectors and imaging systems.

The 1980s - Improvements in Video and Color Technologies

Until the early 1980s, most video image displays came from 'black and white' (more correctly described as grayscale) tube systems, but these gradually began to be superseded by multiple-channel, false-color composite CCD-camera systems in the early 1990s. Until about the mid-1980s, the assignment of colors to grayscale images resulted in rather unnatural, too-dull or too-bright images that appeared unpleasant to human observers. However, by about 1987, color assignment to various tonal values of gray in specified regions had improved to the point where satellite and other aerial images of water and land, while not 'natural' in the strictest sense, nevertheless matched more closely with human perceptions of aesthetic reality. Multiple CCDs are now commonly combined and synchronized to provide multispectral images.

The early 1980s also saw the design and evolution of significant remote technologies: remote computer terminals, remote-controlled robots, and remote-controlled or unpiloted aerial vehicles (UAVs); the latter are often designed with infrared sensor capabilities. These vehicles were seen as a low-cost, low-risk-to-life alternative and adjunct to large-scale aerial reconnaissance planes and were commonly equipped with infrared technology. Their development continues at the present time.

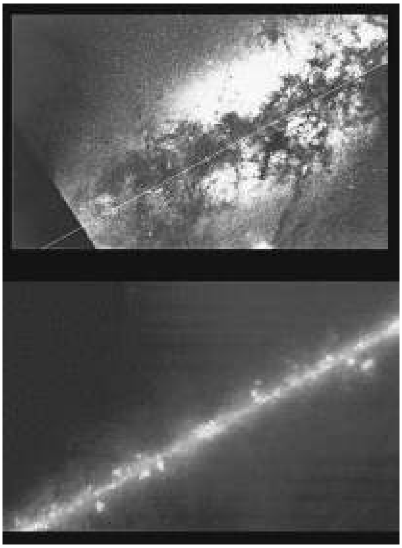
The development and application of infrared sensors continued in the 1990s with the U.S. military's Tactical Airborne Reconnaissance Pod System (TARPS), intended to replace the RA-5C and the RF-8G. TARPS included an AN/AAD-5A infrared line scanner. The TARPS tactical photography system can be mounted under aircraft such as the U.S. Navy F-14 Tomcat. The Tomcats came into production in the early 1970s and have been used for intelligence operations for the carrier battle group, domestic disasters (earthquakes, tornadoes), and international conflicts (e.g., NATO operations).

In the 1980s, significant improvements in imaging quality and resolution occurred, related to improvements in computer imaging and display technologies.

In 1983, the Space Shuttle Columbia used the ESA Spacelab Metric Camera to take overlapping aerial color infrared photographs with a modified Zeiss RMK A 30/32 camera, including some of Mt. Everest. Much of the camera control of the large-format camera was handled remotely, from the ground.

By the late 1980s, still video was being used in military reconnaissance. Although the resolution of early systems was fairly low, it offered the advantages of filmless photography, and the potential of realtime systems (which became available within a few years). Overlapping the improvement of still video technologies was the development of digital camera systems, which began to be implemented in the early 1990s. Improved imaging and software and reduced storage prices contributed to the development of digital imaging systems. Digital imagery offered much higher image resolution than traditional analog video. Digital sensor arrays were installed on traditional single-lens reflex cameras, and within a few years dedicated digital camera systems were being developed for military and commercial applications. The price of digital camera systems continued to drop.

Off-the-shelf computer systems were now commonly used for reconnaissance image processing and system control, whereas in previous years, large, expensive, dedicated systems were more common.




Left: Two images of our Milky Way galaxy, taken in 1983, show how dramatically our perspective can change when things are viewed with other imaging technologies. The infrared image (bottom) allows the galaxy to be seen with less of the 'haze' and dust that interferes with traditional visible light images (top), revealing the slender side-on disc-shape of the galaxy. Right: This remarkable infrared image of the Earth from about 1.32 million miles away was taken during the Galileo Orbiter spacecraft mission in December 1990. The infrared image was taken using light with a wavelength of about 1μ (1 micron), which allows the rays to penetrate through the haze that is associated with Earth's envelope and thus gives a clearer picture of the surface features. South America and some of the eastern seaboard of the U.S. are pictured here. [NASA/Ames Research Center news photos, released.]

The 1990s - Improvements and Broader Applications

In the 1990s, infrared technologies improved and widespread access to commercial infrared detecting devices, data, and images became more readily available.

By the mid-1990s, pixel arrays had improved to the point that they were similar to traditional TV screen resolutions and output formats included a common video format called RS-170. PtSi (platinum silicon) megapixel formats of 1040 *x* 1040 had been developed by 1991.

Also in the mid-1990s, as 'smart missiles' and other forms of advanced weapons and missile-tracking systems were developed, or purchased and deployed by warring nations, it became apparent that photographic forms of reconnaissance and intelligence-gathering were not sufficiently fast or flexible to meet all the needs of war-zone activities; realtime or near-realtime intelligence systems support was needed. The U.S. Advanced Tactical Air Reconnaissance System (ATARS) represents one of the evolutionary steps from traditional systems to day or night near-realtime, data-linked, digital and infrared systems. Thus, intelligence could be gathered from reconnaissance fighter planes with less risk of danger from unfriendly ground-fire. The German Air Force IDS Tornado, also equipped with a reconnaissance system incorporating an infrared linescanner, serves a similar function.

Sensing equipment can be bulky and expensive. When the systems have to be mounted on aircraft or spacecraft with limited space for instruments, it is particularly important to reduce the size and weight of the systems. In some cases, microcomputer technology has aided in developing more efficient systems, but sometimes innovation solves the problem. Since visible and infrared technologies share many aspects in common, inventors devise ways to image both spectra through some of the same components.

Select mirrors, which allow input to be alternately toggled among sensors (e.g., visible and infrared) allow more than one type of input to be imaged by toggling back and forth among them at very high speed. Since the human perceptual system can only resolve about 30 frames per second, multiple inputs to multiple monitors (or a single monitor in which inputs are superimposed one upon the other, or viewed in separate windows) from the same source at anywhere from 20 to 30 or so frames per second will appear naturalistic. Since visible data and infrared data are not received at the same rates (visible data rates may be up to 10 times faster), compensations in frame display are often made for multisensor inputs. While display systems work well at frame rates of about 30 fps, scanning rates need to be much higher, especially if the imaging system is mounted in a fast-moving aircraft.

Pushbroom technologies, imaging systems that create an image line-by-line, began to give way to *framing technologies.* Computer processing improved as well, along with motion-compensation components and algorithms.

Missile-detection systems projects continued throughout the 1990s. In one collaborative project, DARPA, the U.S. Army, and the U.S. Navy developed the Infrared Search and Track (IRST) system. This was an advanced infrared focal-plane array sensor which, when combined with signal processing, could detect incoming test missiles without any false alarms. It was determined to be an effective countermeasure that might be particularly suitable for the defense of marine vessels.

Missile-guidance systems based on infrared sensing were also being developed or requisitioned for purchase by more than a dozen nations. To counter these missile threats, Australia, Canada, the U.K., and the U.S. jointly participated in the MATES project, in the mid-1990s, developing a means of effectively breaking the track of an infrared missile-seeker, thus providing a missile countermeasure.

By the late 1990s, almost 40% of the budget of the Advanced Technology Development program was allocated for electro-optical/infrared countermeasures technologies.

Politics and Aerial Surveillance

Infrared has become an essential aspect of aerial surveillance. Almost every major type of aerial imaging platform carries at least one infrared sensor and some carry multiple sensors. These systems map and surveil the Earth from both the upper atmosphere and from space. By the 1980s, aerial surveillance had become not only a tool of science, but also a tool of business and government, for observing and monitoring the planet and the activities of other nations.

The 1980s and 1990s were a time during which nations all over the world realigned themselves. New nations were created through the breakup of the U.S.S.R., Czechoslovakia, and Yugoslavia. The European common market, which had been negotiated for decades was finally starting to come together. Political boundaries and alliances shifted in Africa. The relationship between India and Pakistan became more strained. The overrun of Tibet by China came to the attention of the western world. All this shifting of political power and political boundaries created a greater emphasis on surveillance technologies, particularly those which would facilitate the monitoring of local political instabilities and national borders. Diminishing resources and border realignments also motivated the monitoring of local and international poaching and resource exploitation.

Further Improvements in Technology

During the 1990s, computer electronics and storage devices continued to improve in capacity and resolution and to drop in price, facilitating dramatic improvements in sensing and imaging systems.

Infrared sensing chips gradually became optimized for specific purposes, compared to earlier generic chip technologies. Clock and bias generation capabilities were streamlined and functionality was added in other areas. Electronic zoom capabilities were added to staring sensors.*

Throughout infrared history, there has been a search for materials that would provide greater ranges and could be used at or near room temperature. Progress was made in both these areas.

Through the 1980s and the 1990s, tremendous strides were made in large-bandgap, compound semiconductors. This helped in the implementation of quantum-well theory in a physical medium. Subsequently, quantum-well infrared technology began to have a practical impact, permitting the development of commercial products with higher sensitivity levels in long-wavelength infrared.

Military Surveillance

The improvements in technology were always of interest to the space sciences and the military, as they permitted smaller more sensitive instruments to be used.

Infrared sensors are used in many military reconnaissance systems mounted on aircraft and these are described in more detail in the Aerial Surveillance chapter. They are also used in missile-targeting systems, described further in Section 6 (Applications).

In 1992, the U.S. Navy initiated *Project Radiant Outlaw,* a demonstration project for long-range noncooperative identification (NCID) of a variety of ground and air targets. The project included a multisensor combination of laser radar (ladar) and a shared-aperture staring focal-plane array infrared sensor operating in the mid-range of 3.8 to 4.5 µm [Shen, 1994]. Thus, high-resolution, staring, passive infrared was combined with the other sensor technologies for use in various types of identification. Later, the *Infrared/Electro-Optical Long-Range Photography System* (IR/EO-LOROPS) project was initiated by the Navy to meet the need for long-range standoff digital infrared reconnaissance missions.

Infrared Applications in the Space Program

Many of the U.S. space missions have been directly involved in the development of infrared technologies and some have carried infrared cameras and telescopes out into space as scientific and commercial payloads. Many different types of sensors have been evolving in step with other aspects of the space program. Ultraviolet and gamma-ray sensors were also becoming more important in the 1990s and are described in the Ultraviolet Surveillance chapter.

During the late 1990s, newer, more powerful infrared equipment was used in many industries. In the U.S. space program, a milestone was reached in early 2000 when a new thermal-infrared (TIR) imaging system carried aboard ASTER gathered images of Earth from space that were taken at night. Visible/near-infrared systems couldn't take pictures of Earth from this distance at night for various technical reasons. On Earth's surface a source of infrared light can be shone at a photographic subject if there is insufficient infrared to register on the film. This solution is obviously impractical, however, when great distances are involved as in space missions. The TIR system overcame previous limitations by sensing a region of infrared that is radiated from the Earth and is present without supplemental infrared light, allowing a new era of 'dark-side' imaging to begin.

*Paul R. Norton provides information on photodetectors across a range of frequencies, including infrared, in Chapter 15 of Bass, Michael, Editor in Chief, "Handbook of Optics," listed in the Resources section.

In the summer of 1997, the crew of the Space Shuttle Discovery completed a one-and-a-half week mission in which part of their job was to deploy the Cryogenic Infrared Spectrometers and Telescopes for the CRISTA-SPAS-2 satellite to aid in researching the Earth's middle atmosphere. [NASA/KSC news photo, released.]

Late 1990s - Increased Sophistication and Commercialization

The U.S. Army teamed up with Indigo Systems Corporation of California in 1997 to develop the world's smallest infrared camera, resulting in the UL3 alpha that was announced in 1999. The tiny six-ounce camera is sensitive to infrared radiation in the 8 to 12 µ waveband. The camera is so small and low in power consumption, it can be used as a sensor or as one unit in a group of sensors to guard minefields or other restricted areas. It is also small enough to be placed onboard some of the newer, smaller unpiloted aerial vehicles. The camera is also being evaluated for firefighting applications, since infrared can penetrate haze and function in darker environments more readily than visible light. It may also be able to detect 'hot spots' in buildings that are not otherwise visible.

Many infrared devices are now inexpensive and easy to manufacture, and are used in commercial and industrial settings. By the year 2002, they will probably become commonplace in small businesses and multiple dwelling units. As prices drop, they are likely to be purchased as home consumer appliances for family and individual use. One of the more obvious commercial uses of infrared sensing is for fire detection, but security and imaging applications are likely to be popular as well.

At the present time, research in sensor technology continues in the search for faster, lower-cost imaging systems, high-resolution, high-sensitivity color imaging arrays, and sensor suites that can work with multiple wavelengths. Quantum-well and other new semiconductor technologies show promise. Very-high frame rates (which are especially important in equipping high-speed craft) up to at least a thousand frames per second are now considered desirable. Detection of a target within clutter, that is against a confounding background, is still ongoing research and will continue to be an area in which improvements will be welcome.

The Night Vision and Electronic Sensors Directorate of the U.S. Army and Indigo Systems Corporation teamed up to create the world's smallest infrared camera, tiny enough to be used as perimeter sensors, helmet-sensors, and infrared imaging components on remote-controlled and autonomous aerial vehicles. It is also being evaluated for fire-detection applications for businesses and fire services. [U.S. Army/Indigo Systems Corporation 1999 news photos, released.]

5. Description and Functions

The basic types of infrared sensors have been described in earlier sections of this chapter. Some further distinctions and examples will be presented here.

5.a. General Categories and Distinctions

It is common to describe commercial equipment in terms of certain 'landmark' improvements in sensitivity or capabilities so that consumers and users can distinguish one device from another. The designations of 1st or 2nd *generation*, for example, help distinguish newer, more powerful technologies. As the generation number increases, so usually does the price, but this is not always true, because of breakthroughs in electronics. In general, infrared and night vision products are described as follows:

generation 0 - Active night vision systems which require supplemental illumination. Electron acceleration is used for gain.

generation I - Passive systems which do not require supplemental illumination and which do not employ a microchannel plate. The peak response is in the visible spectrum. Electron acceleration is used for gain.

generation II - Passive system which do not require supplemental illumination but which employ a microchannel plate* for gain.

generation III - Gallium arsenide photocathode devices which employ a microchannel plate for gain. High photosensitivity and broad-spectrum response.

Quantum-well technology is one of the more recent and interesting developments in infrared sensing science. Computers can do highly complex operations and calculations based on a simple binary system. Similarly, quantum-well technologies can be stacked in such a way as to provide a structure in which the quantum energy states are limited to two states, ground and excitation, in essence, a simple but powerful binary system. Thus, an infrared detector

*A microchannel plate (MCP) is a perforated glass disc positioned behind the photocathode. This arrangement provides electrons to aid in gain and is characteristic of Generation II and Generation III night vision systems.

with a sharp absorption spectrum can be designed and particular wavelengths can be singled out by tailoring the dimensions of the well.

Infrared Sensors

Infrared sensors come in many different forms, from simple thermometers to sophisticated detector arrays in which the radiation striking the detectors triggers a process in which the energy is converted to an electrical signal which is then further processed, recorded, and/or displayed. For imaging systems, the trend has been to assemble denser and larger arrays to increase image resolution. Higher frame rates, more sensitive detector technologies, and better software for distinguishing target/noise distinctions are also being developed.

Although mirrors are used in many infrared devices, they must be made to reflect infrared. Glass tends to absorb radiation through most of the near-infrared spectrum and thus must be coated with a metal such as silver or aluminum. Essential transparent materials are typically made of highly polished transparent mineral materials other than glass (e.g., quartz) in order to keep scattering to a minimum.

5.b. Photography and Imaging

Cameras

There are two general categories of cameras used as infrared technologies:

Film cameras that take conventional-style photos (these record reflected infrared and cannot record passive infrared sources at night, for example, without a source of infrared illumination) and *sensor-based cameras* (such as video imaging cameras) that are equipped to do thermography. Since film cameras work with reflected infrared, a source of infrared light is needed as a source of illumination. Standard cameras with glass lenses can only be used to record infrared frequencies near the visible spectrum (near-infrared). Wavelengths greater than about 1 µm cannot be captured with standard lenses and films.

Specialized infrared cameras for wavelengths of 4 µm or longer which may use a one-dimensional array of solid-state detector elements, with one- or two-dimensional mechanical scanning, with a resolution less than that of traditional television. Traditional infrared cameras sense only to about a wavelength of 1 µm. Long-range detectors use special semiconductors (e.g., Mercury-Cadmium-Telluride) to sense up to about 4 µm or, if cooled cryogenically, sometimes can sense warm objects up to 12 µm. Each detector requires an individual amplifier to magnify the minimal output voltage, thus creating a somewhat nonuniform image from line to line [Beam, 1989].

Tube-based infrared-sensing systems tend to be more sensitive to infrared than film, but have the disadvantage of lower resolution. They detect visible and infrared wavelengths up to about 0.85 µm [Lo, 1986].

Regular cameras used for shooting infrared photos typically use film sensitized to infrared in the 0.7 to 0.9 µm region of the electromagnetic spectrum or broadband film with filters to screen out most of the visible spectrum and all of the ultraviolet. Grounding may be necessary to reduce the chance of static discharges inside the camera that might affect the film.

Some off-the-shelf cameras are more infrared-film friendly than others. The Canon EOS cameras, for example, have an infrared film-loading mechanism. It has been reported by photographers that it will fog part of the outside edge along the film-tracking section (the guide holes), but that the fog bleeds only marginally into the image area.

Light Meters

Regular light meters are not appropriate for use with infrared, as they are optimized to monitor the values within the visible spectrum. Built-in meter systems in standard cameras can be used, sometimes with an infrared filter in place, as long as the compensations described below are used. Specialized infrared meters are available, at higher prices.

You can learn to compensate regular metering, but it is important to use a camera in which the automatic metering can be turned off and manual settings used. Most of the inexpensive pocket cameras aren't suitable, but many 35 mm cameras have manual overrides. The depth of focus is different for infrared than for visible light, so many swappable lenses have a little red tickmark adjacent to the focus mark that indicates the amount of adjustment to make to the focus for infrared photography, when shooting with an appropriate infrared filter.

Broadband infrared filters are opaque to visible light. In other words, our sensory equipment (our eyes) can't see through them. This makes it hard to focus and frame a shot with an infrared-blocking lens through a single-lens reflex camera. A red or yellow filter lets you see the scene, but is not sufficient for pure infrared photography, because it allows some wavelengths of visible light to penetrate the lens. However, for some special effects or situations, a colored filter might provide the desired effect in a photo.

When photographing infrared, smaller aperture settings (higher *f*-stops) are preferable, approximately f/11 to f/22.

It is highly advisable to shoot at least one test roll and to record the results so that you can analyze them and compensate appropriately on future rolls. If you are planning to use more than one type of filter with more than one type of film, you may have to do several test rolls, and should probably do tests that are metered both with and without the filters in place. However, if you are planning to shoot with one filter and type of film (which is a good way to get started), then you can meter through the filter, bracket the exposures (shoot two settings over the indicated *f*-stop and two under it, in addition to the metered *f*-stop) and run a test roll. If the negatives are too light or too dark, compensate and run another test roll.

Metering without the filter and then adding the filter and bracketing are sometimes recommended (and make sense if you will be switching filters frequently).

Filters and Focusing

A Wratten 87, 87C, or 89B filter is called a *cutoff* filter because it only lets through infrared radiation, screening out the visible radiation. This provides the closest to a 'true' infrared picture. However, if some visible light is acceptable, or desired for focusing in daylight, a Wratten 25 can be used as a second choice. It won't block all the visible light (red still passes through), but it will screen out the blue and ultraviolet wavelengths.

A yellow filter is used to screen out Rayleigh scatter (the particle scatter that makes the sky seem blue to us) [Lo, 1986].

The focal distance for infrared is different than that for visible light due to refractive differences. It helps to use wider-angle lenses in order to increase the depth-of-field, and to use lenses with the little red tick mark that indicates infrared focusing compensation. (You may have wondered what that little mark on the lens was supposed to mean.) As long as automatic focusing (AF) settings on the camera can be overridden, you can usually get an initial reading through an appropriate filter and then manually adjust the focus before taking the picture. Once the film is loaded, it is best to change lenses in the dark (under a blanket or in a closet, or under a coat if it is being used out in the field) and to keep it away from heat sources.

Infrared Film and Processing

Infrared film can be purchased from photo supply stores on and off the Internet. Most infrared films are available for 35 mm cameras in 36-exposure rolls, and some are available in both rolls and sheets of different sizes. Some infrared film is specialized for aerial photography, with cutdown versions for conventional cameras.

Infrared film must be handled carefully. Just as visible *light* can fog regular film, *light and heat* can fog infrared film. Film cassettes *must* be handled in complete darkness. Unlike visible light which is blocked by the film cassette, infrared can penetrate the cassette (don't hold it in your warm hands too long or handle it near heat sources).

Some smoke detectors, motion detectors, and darkroom lights emit infrared, so take care to avoid these as well. Don't open the film cannister in the light either before or after the film is exposed, even this must be done in a closet, darkroom, or under a dark blanket.

Purchase the film only from a reputable supplier familiar with the storage and handling of infrared film. The film must be kept cool before and after exposure until the time it is processed. If it has been refrigerated, allow it to adjust for an hour or so to the ambient temperature before exposing the film to reduce the chance of condensation.

Some infrared films have an *antihalation* layer. Halation is haloing, fringing or fogging, that is, the spreading of the exposure beyond the area desired. An antihalation layer offers a bit of protection against undesirable exposure 'bleed' or film fogging.

Infrared film records infrared light that is reflected off objects within certain wavelength ranges. Infrared is absorbed by such things as trees, rocks, and soil. Cool objects emit less infrared and warmer objects (people, animals, fire, electrical sources) generally reflect or radiate more infrared. The levels of contrast between the bodies that absorb or radiate infrared are recorded as different 'light' values in black and white infrared film and as different colors on infrared color film. Thus, people crossing a border at night (assuming that a source of infrared illumination is supplied) will appear as light-colored ghosts against trees or water that are cooler and hence will appear darker on black and white film.

Most commercial infrared films are sensitive to infrared, visible spectrum, and ultraviolet light. They tend to be a little less sensitive to green light (the dominant region of the visible spectrum). Filters can be used to exclude most or all of the visible spectrum and some or all of the ultraviolet radiation. Infrared wavelength sensitivities for film are usually expressed in nanometers (nm). 1 µm = 1,000 nm. Some common commercially available infrared films and nearly infrared films follow.

Black and White Infrared Film

Most infrared images are shot in black and white. Use of multiple exposures, different filters, digital image processing, and hybrid techniques can be used to yield *false color* images, but many are left unchanged, as black and white is suitable for a wide variety of applications.

Black and white infrared film is convenient because it is readily available and can be processed with standard black and white processing (with the proviso that the cannister be opened in total darkness away from heat sources). Do not trust your infrared film cannister to technicians who are unfamiliar with its handling; even if you tell them not to open the cannister, they may do so because they don't understand the technology and the risks of fogging through the film cassette. Choose an experienced lab or process it yourself.

Agfa APX 200s - This has a spectral sensitivity from below 400 nm to about 775 nm. It peaks at a level similar to the Konica Infrared film, about 725 nm.

Ilford SFX 200 - This is a red-extended-sensitivity film rather than a true infrared film used more for art photography than surveillance, but it has some interesting properties. It is panchromatic to about 800 nm. It can be used with a red filter for infrared-type pictures. Since it is a visible spectrum, somewhat-infrared film, it is easier to handle and less subject to fogging due to its lower infrared sensitivity.

Kodak High Speed Infrared (HIE) - This is one of the most well-known films for infrared photography. It is a moderately high-contrast ESTAR-based film available in a variety of sizes in rolls or sheets. Kodak HIE is sensitive to about 900 nm. It must be handled carefully so as not to expose it to infrared sources (including reflective surfaces on the back of the camera) and does not have an antihalation layer. Kodak recommends an exposure index (EI) of 50, but it can be used at higher EIs to create more pronounced effects. It is a little grainier than Konica Infrared and not necessarily the best for enlargements but, on the other hand, is faster and readily available.

Konica Infrared 750 - This has two peak sensitivity ranges, at about 400 to 500 nm and about 640 to 820 nm. It peaks at about 750 nm. It includes an antihalation layer to facilitate handling. This is a slower film than the Kodak HIE and is not suitable for fast-moving objects, but is probably the most commonly used film after the Kodak HIE and is chosen when a finer grain is desired.

Color Infrared Film

Color infrared film is typically composed of color-sensitive layers in the three primary colors for light (red, green, blue - RGB). Infrared red film has an additional layer that is designed to be sensitive to infrared radiation.

Kodak Ektachrome Infrared IE - This color infrared film was developed for aerial photographic imaging. Exposures should be made with a Wratten 12 filter for preferred colors. The images will not look like regular color film as the colors match infrared energy levels rather than visible light colors as we know them, but you can get used to interpreting the colors with a little practice. For aerial and scientific processing, AR-5 is used. For regular slide processing, E-4 or E-6 can be used (the colors will be a little more saturated which might serve some publication or aesthetic purposes). Check the instructions that come with the film before processing. It is sensitive up to about 900 nm.

If only infrared is to be sensed, a visible light filter is used over the lens to block the visible light.

Don't use automatic DX-coding in the camera, use a manual setting, if possible, in order to avoid the possibility of fogging from the DX scanning sensor.

6. Applications

Anything which emits heat, or patterns of heat, can be subjected to infrared observation. In some wavelengths, a secondary source of illumination may be necessary. Thus, surveillance of people in a large variety of settings is a common application. Infrared sensors can be used to monitor employee movements, possible intruders, stowaways, and border runners.

Infrared sensors can be used in many commercial applications: ensuring the safety of amusement park patrons around rides; monitoring visitors or employees around heavy equipment or potentially dangerous chemicals; watching law enforcement containment areas; sensing hostile intrusions in combat areas; detecting smuggling or other covert illegal operations; medical imaging, diagnosis, and monitoring; surveillance of physical characteristics or changes, including electrical, structural or mechanical fault detection and monitoring; and chemical process monitoring.

Illumination

Just as you need a light to see objects when the sun isn't shining, you need infrared lights to see objects that don't actively emit infrared radiation.

Many types of infrared technologies require a source of illumination in order for the reflected light to be sensed. Infrared film photography is one example. Thus, illuminators are commercially available for wildlife observation, border patrol, maritime surveillance, search and rescue, and low- or no-light infrared photography or live surveillance.

Infrared illuminators fall into two general categories:

continuous lights - These are similar to conventional light sources which emit a continuous beam. They are used to illuminate a source being observed or photographed which does not inherently emit infrared radiation in the wavelengths necessary to activate a detector. Illumination sources are especially useful at night. Visible/infrared lights in the 40 to 50 feet range commonly cost about $150 to $200. Short-range infrared laser illuminators are in the $1,000 range. Long-range illuminators (up to about 11 miles) suitable for marine, desert, or plains applications are priced around $5,000 to $20,000.

pulsers - These illumination sources emit continuous or pulsed signals and are typically used for identification, marking, or tracking devices that are specially designed to be detected with infrared viewers. Pulsers for many typical applications are in the $60 to $800 range.

Common sources of illumination include light-emitting diodes (LEDs), filtered incandescent light sources, and laser light sources. Illuminators vary in size, and may be portable or stationary, powered by batteries or 110/220 AC wiring. High-intensity infrared searchlights may use xenon bulbs for greater range. The beam-width of an infrared illuminator may be fixed or adjustable, with adjustable varieties usually being in the higher price ranges.

Night-Vision Scopes and Goggles

Night vision equipment is one of the more popular categories of surveillance accessories. Many clandestine activities happen at night, as do animal activities, bird migrations, and other areas of research and observation. Night vision scopes consist of a variety of types of binocular and monocular sensor-equipped optics.

Night-vision scopes are not necessarily infrared-equipped. Some of them are basically *light-amplification systems* which boost light sources in low light so they can be more clearly seen. Those which amplify light in the visible spectrum cannot 'see in the dark' as the name might imply. Infrared-sensitivity modifications and a supplemental source of infrared illumination are needed for true 'night vision.'

True infrared and infrared-sensitive or visible-spectrum night-vision scopes are common in a variety of applications. Depending on the type of system, they are used to detect people (poachers, border-runners, smugglers, snipers, lost hikers), animals (game, endangered species, injured livestock, lost pets), and sources of heat (electrical wiring, steam leaks, insulation gaps, structural stresses, arson, and forest fires).

The range of a scope will vary with the lens magnification (as in telescopes and binoculars) and the amount of available light. Ranges of a few hundred feet are common. However, in total darkness, supplementary infrared illumination is required, and even then, the range will be reduced to about 100 feet.

Night vision scopes based on phosphor-activating tubes do not last indefinitely and their lifetime may be reduced if they are subjected to frequent extended bright lights (which can cause burn-in just as might happen on a television or computer monitor). Similarly, and more importantly, the image intensifier is subject to aging, lasting perhaps 1,000 hours, depending on the system. Reconditioned or used night-vision equipment should not be purchased unless you know the circumstances under which the device was used, and for how long.

If you are planning to ship or travel with night-vision equipment, check customs and export/import regulations, as many scopes are subject to export restrictions.

Since scopes are typically portable, most of them run on batteries. Depending on the style and size of the scope, the battery life may range from 10 to 40 hours. Most consumer scopes use AA or lithium batteries. Battery-operated handheld viewers may be used in conjunction with infrared lasers or coils. Common applications include fire detection, security, fluoroscopy, night vision, pursuit, film manufacture and processing, and mineralogy.

Equipment and Accessories

Optional lenses, filters, mounting brackets, tripods, and light sources are available for many infrared viewing products, ranging in price from $20 to $1,600. Generation I scopes are typically about $700 to $900. Generation II and III scopes are about $3,200. Some scopes have camera adaptors and some are self-contained. The higher-priced devices generally have better water-resistance, better changing-light compensation, and bright-light-cutoff safety features. They may also feature longer battery life.

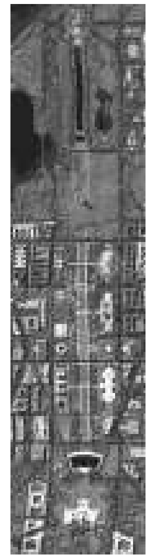
The smaller pocket-scopes that can be used in conjunction with video and still cameras start at around $200 (Gen. I), $2,000 to $4,000 (Gen. II), and $4,400 (Gen. III). These scopes typically have a detection range of up to 200 to 450 feet.

Mapping and Topolographic Studies

The mapping field is rapidly evolving and changing due to dozens of new sensing technologies that can be used to gather data. In addition to sensors, we have also developed new methods of transportation, higher resolution image recorders, better printers, and more sophisticated image processing methods. There have never before been so many ways to access and record locations on and beyond the Earth.

Maps are no longer limited to hand-drawn renderings of streets and elevations. They now include photographic satellite images of over 80% of the Earth. They show details of countries that have traditionally been closed to foreign travel and western surveys, including buildings and farms. They chart archeological ruins and cave paintings that are invisible to conventional technologies but become visible through infrared, ultraviolet, or radar probing. They are enhanced and processed with computer algorithms and paint programs. Judging by the current rate of change, the technologies and techniques for mapping are likely to continue to evolve dramatically in the next couple of decades and infrared imaging is an important aspect of that development.

Near-infrared has many applications in infrared imaging systems, but it cannot provide night images without supplemental illumination. This makes it unsuitable for some types of imaging, including pictures of Earth taken from the upper atmosphere or from space.



Left: An aerial view of the Red Sea that was taken at night by ASTER, using a new thermal-infrared (TIR) imaging system. (Visible/near-infrared systems require illumination and thus cannot be used for this type of night imaging.) Lighter areas indicate regions where temperatures are higher. This is the first ever spaceborne TIR multiband sensor, a joint project of the U.S./Japan Science Team. Right: Computer scientists, like professor David Landgrebe at Purdue University, are working on computer algorithms which can automate image processing to the point where consumers can make use of technical images available from satellites and other sources of infrared. These tools, which allow particular sorts of structures, rooftops, roads, vegetation, etc. to be more easily distinguished, will add another level of information acquisition to imaging devices. Shown above is a color infrared photograph of the National Mall in Washington, D.C. that is a candidate for this type of analysis. [NASA/Goddard/ERSDAC/JPL Feb. 2000 news photo; Purdue University 1999 news photo, released.]

Infrared Spectrometers and Reflectometers

Spectrometers are scientific/industrial instruments that are used for many purposes, from studying atoms and molecules to studying the various wavelengths that are emitted by light sources. Since different substances emit different spectral patterns, spectrometers can be used to detect and identify these patterns, which makes them useful in analytical chemistry, gemology, law enforcement, and forensics.

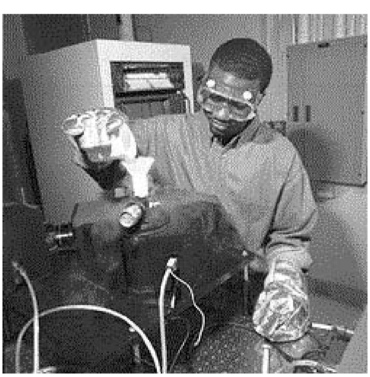
Spectrometers are sometimes used to determine the quantities of certain substances that are present in a sample. For example, the Bureau of Tobacco, Alcohol, and Firearms (ATF) makes sure that the quantity of carbon dioxide added to still wines by producers does not exceed regulated maximum limits. An infrared spectrophotometer is used to determine the amounts of CO_2 present, to make sure they comply with regulations.

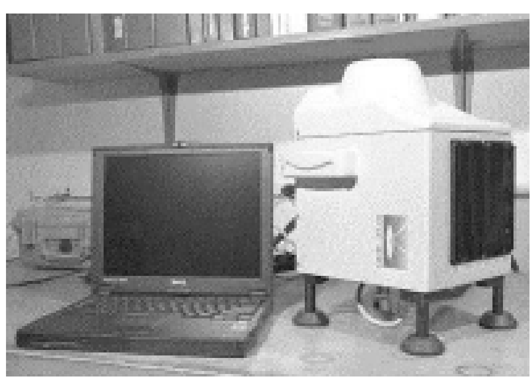
Just as the visible spectrum has different wavelengths that are perceived by us as different colors, the infrared spectrum has different wavelengths that can be measured for their different spectral characteristics. This is useful in many different fields.

Spectral analysis can be used for chemical identification in pharmaceutical applications and law enforcement (e.g., drug identification). It can be a useful tool for production line automation, quality control, and quality/composition inspection.

Left: A computerized infrared imaging spectrometer used in space sciences. Right: An infrared image taken from onboard the NASA Galileo spacecraft while viewing one of Jupiter's moons named Io. Images like this are sometimes taken simultaneously with two different types of imaging systems, with the pictures superimposed to give a better view of the various features. The spectrometer detects heat from sources such as this active volcano by imaging them in near-infrared. [NASA/GRC 1996 news photo by Chris Lynch; NASA/JPL 1999 News photo, released.]

Spectral analysis is used by astronomers to learn more about distant planets. By analyzing the radiation emitted by planets as much as 100 light years away, it is possible to make educated guesses as to their atmospheric makeup which might include carbon dioxide, water vapor, and ozone. This aids in the search for other life in the universe and may someday help us locate other habitable planets. Since the Earth emits a considerable amount of infrared radiation, it interferes somewhat with spectral analysis from Earth-based telescopes. For this reason, space-based telescopes are also used. NASA has shown that by combining more than one telescope, it may be possible to create a space-based *interferometer* that could collect planetary infrared light with far greater effectiveness than land-based telescopes. The precision of the Space Interferometry Mission (SIM) telescope is so high, NASA claims it would be sufficient for someone on the Earth to "see a man standing on the Moon, switching a flashlight from hand to hand." This is clearly a high level of surveillant capability.





Left: Craig Washington servicing an infrared imaging spectrometer. Right: This is a portable version of an infrared reflectometer. Portable systems are always in demand because they can be mounted in smaller compartments and used in research and field work where it is difficult or impossible to take bulkier equipment. They also tend to consume less power. [NASA/GRC 1996 and 1999 news photos by Christopher Lynch, released.]

Quality Control, Assessment, and Inspection

Infrared has many industrial surveillance applications. It can be used to assess materials composition, uniformity, and to see structural anomalies that might not be apparent with other methods of inspection. It is frequently teamed up with other sensing technologies. In the early days of rail inspections, magnetic sensing was used to try to locate defects in individual pieces of track. Eventually ultrasound was found to be an effective technology for revealing problems before they could be detected visually. A whole array of sensing systems, including infrared, is now used for industrial inspection and assessment.

Infrared has been particularly valuable in electrical inspections, since there are many instruments for detecting thermal infrared. Thus, infrared detectors can be used for locating 'hot' wires or other electrical anomalies that might be dangerous. It can be used for assessing stress and wear and tear on production machinery. It is also useful in structural inspections outside of factories and is now being used to inspect bridges.


Lawrence Livermore National Laboratories (LLNL) has developed a mobile infrared-based construction inspection system. An engineer sits inside the moving vehicle of the prototype bridge-deck inspection system illustrated here. He is monitoring the data gathered from two infrared cameras that are mounted on a boom on the outside of the vehicle. Images of the road surface are transmitted to the computer inside the vehicle, which records and analyzes the images for temperature differences that might indicate cracking or rebar corrosion beneath the surface of the bridge deck. [LLNL news photo by Don Gonzalez, released.]

Fire Detection

Infrared sensors are well-suited to detecting thermal radiation in the infrared ranges that we perceive as 'heat.' This makes them valuable for monitoring industrial and scientific environments where heat-monitoring is critical for the protection of instruments, structural materials, and people. It also makes infrared sensing an excellent tool for detecting potential electrical hazards (hot wires) and for detecting fires in urban or forested areas.

Infrared forest fire detectors can be readily mounted on aircraft or all-terrain vehicles. Compact fire detectors can be mounted on walls or ceilings in buildings and can now be interconnected through computer distribution networks so that potential fire conditions can be relayed to security stations or a central console. The data could potentially even be sent through the Internet to local fire fighters.

Electronic fire detection systems could also be designed to send messages and instructions to people in specific areas of a building if danger were detected, reminding them to stay calm, to stay out of elevators and to evacuate quickly through specified exits.

This well-shielded infrared imaging system is a bit larger than a basketball and is designed to mount on the side of a helicopter. The infrared sensing has been incorporated as a forward-looking infrared radar (FLIR) fire-detection system. A realtime TV monitor inside the craft allows personnel to monitor the data. The FLIR collects thermal images and temperature data in conjunction with exact location readings from a Global Positioning System (GPS) monitor inside the helicopter. This equipment aids security and safety around the Kennedy Space Center, especially prior to launches, and supports Florida's Division of Forestry in fighting brush fires. [NASA/KSC 1998 news photos, released.]

Astronomy

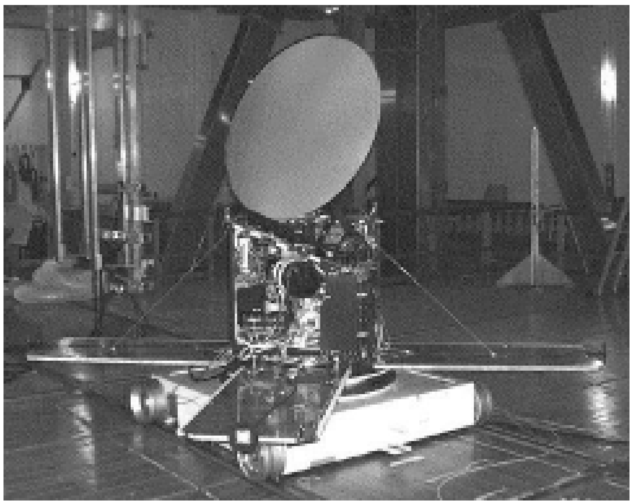
Infrared sensing is an integral tool of astronomers and space travelers. Various infrared wavelengths are emitted by cosmic bodies and can be analyzed to help us observe and understand the universe. Space and ground telescopes use a variety of types of cameras. With varying filters and exposure times and combining the images, spectacular three-color composites can be obtained as, for example, near-infrared images from our Milky Way taken by the *Infrared Spectrometer and Array Camera* (ISAAC) cryogenic infrared imager and spectrometer, installed on a VLT telescope in 1998.

The *Mariner 6 and 7 space probes*, launched in 1969, provided a variety of images, including TV photos and infrared and ultraviolet spectral images, as they journeyed out into the solar system past Mars. Also in 1969, *Apollo 12* travelled to the Moon and brought back the TV camera that had been attached to *Surveyor 3* as it perched on the lunar surface for two and a half years. The scientists wanted, among other things, to evaluate the effects of almost three years of exposure to the lunar environment.

The *Hubble Space Telescope* is equipped with an infrared camera which provides images of the cosmos indicating how it may have looked millions and billions of years ago. Regions that were investigated with a visible-light camera were then imaged with a near-infrared camera, yielding evidence of hundreds of galaxies not seen with visible light, some of which were obscured by dust which attenuates visible light. Images from outside the visible range also indicated that what had previously appeared to be galaxies might actually be new star regions within larger, older galaxies [Lowenthal et al., 1997].

The *Diffuse Infrared Background Experiment* (DIRBE) is a cooled reflecting telescope that is sensitive over a broad range of wavelengths encompassing 10 infrared bands from about 1.2 to 300 µm. By spinning the mounting platform, a 360° arc can be swept in each revolution, sampling about half the sky each day for about a year. Instruments for detecting a number of types of waves were installed; including a central instrument called the *Far Infrared Astronomical Spectrograph* (FIRAS).

The *Odin Satellite* is a Swedish-led multinational satellite mission involving Sweden, Canada, Finland, and France designed to conduct sensing and research into astronomy and the atmospheric sciences. The craft is equipped with the Swedish Sub-Millimeter Radiometer (SMR) and the Canadian *Optical Spectrograph and InfraRed Imager System* (OSIRIS). It was launched early in 2000 from Svobodny in Eastern Siberia into a sun-synchronous circular orbit at about 600 kilometers and was expected to have an active lifetime of about two years.

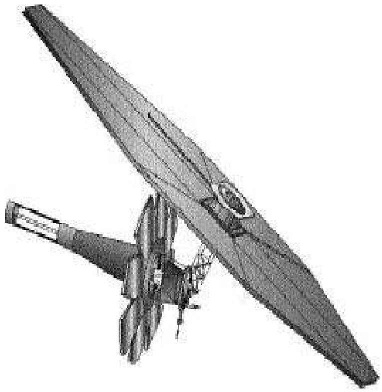


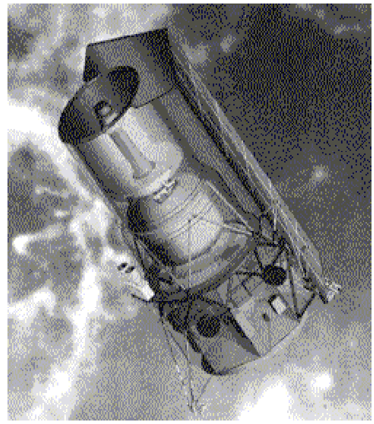
The Odin Satellite is a multinational project which includes the Canadian *Optical Spectrograph and InfraRed Imager System* (OSIRIS) which, among other things, will monitor ozone depletion in greater detail than was previously possible. Odin is showed in its deployed configuration in tests at the System Magnetic Tests, IABG, Munich. The OSIRIS infrared imaging system was designed and built by Routes Inc., Ontario. [Canadian Space Agency/Swedish Space Agency 1999 news photo, released.]

The Odin is equipped with a side-pointing telescope which is shielded and oriented so that it is protected from the Sun. There are also star trackers mounted on top of the upper platform, with subsystems mounted on both platforms. The system gets power from four solar panels fanned out between the shields. The optical spectrometer has four wavelength bands and sensing wavelength windows are 280 to 800 nm and 1270 nm. The infrared optical resolution is 10 nm.

In 1998, the giant *Keck II telescope* in Hawaii used a sensitive infrared camera to observe a swirling disc of dust that may indicate a new solar system being born around a star about 220 light-years from Earth. That same year, the NASA Hubble space telescope imaged a historic long-exposure infrared image of the faintest galaxies ever observed, some of which may be over 12 billion light-years away. This was accomplished with Hubble's near-infrared camera and multi-object spectrometer.

The *Next Generation Space Telescope* (NGST) was designed as a successor to the Hubble Space Telescope. The NGST will operate in a high-Earth orbit so that it will be far enough away to avoid the majority of the thermal heat emitted by the Earth. The operating temperature of the satellite is also intended to be as low as possible so as not to interfere with the astronomical emissions from other celestial bodies.





Left: A concept drawing of the proposed Next Generation Space Telescope (NGST) equipped with infrared-sensing equipment. Right: A model of the Space Infrared Telescope Facility (SITF) intended to overlap Hubble and Chandra X-Ray Observatory operations in 2001. It is being designed with state-of-the-art infrared cameras. [NASA news drawings, released.]

Military Surveillance

The display console and control panel for a *Wide Angle Surveillance Thermal Imager* in use at an air base in Korea. Airman 1st Class Olivia Latham scans the air traffic control tower for infiltrators during a scheduled rear area defense field training exercise. The background sky appears as a yellow color, while the large building on the left and control tower on the right show up as pink and lavender. [U.S. DoD 1999 news photo by Val Gempis, released.]

Infrared detection and imaging technologies are used in many aspects of military surveillance. Infrared sensors and recorders are installed in armored vehicles, reconnaissance planes, portable handheld units, and command centers.

Piloted aircraft and unpiloted aerial vehicles (UAVs) are widely used in infrared surveillance and many of them are described in other sections of this chapter and in the Aerial Surveillance chapter.


The Predator UAV is shown here in a simulated U.S. Navy aerial reconnaissance mission. The craft is launched from the carrier shown in the background where controllers and intelligence analysts analyze the data transmitted by the vehicle. The Predator is equipped with a variety of surveillance technologies including near-realtime infrared and color video imaging systems. [U.S. DoD 1995 news photos by Jeffrey S. Viano, released.]

Aircraft tactical reconnaissance pods carry a variety of surveillance equipment, including infrared sensors to provide imagery in darkness or bad weather conditions in low altitude assignments. Typically these pods are bullet-shaped containers weighing about 1200 pounds that are centerline-mounted under the belly of tactical aircraft. They are usually equipped with several types of cameras, recording devices (e.g., tape recorders) and, in some of the more recent systems, realtime or near-realtime downlink technologies. Examples include TARPS and ATARS. These tactical pods are somewhat self-contained so they can be selectively installed potentially linked to different types of aircraft. The modular design also facilitates equipment upgrades and substitutions, with minimal modifications to the host aircraft.

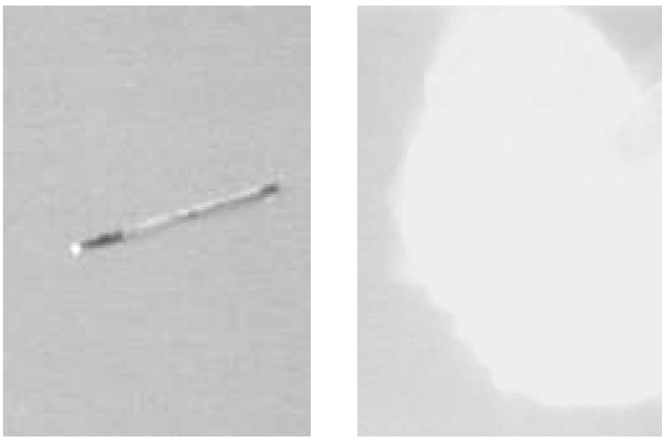


Infrared imaging systems are frequently housed in streamlined ‘pods’ that can be selectively installed under the belly of various reconnaissance aircraft. Left: U.S. Navy mates remove an infrared sensor from a *tactical air reconnaissance pod system* (TARPS) that is attached to an F-14A Tomcat stationed in the Adriatic Sea, in 1993. Middle: A closeup of an F-14D Tomcat shows a double pod under the nose, which is equipped with a television camera system and an infrared search and tracking system. Right: The underbelly of an F-14B Tomcat equipped with TARPS. [U.S. DoD news photos by Todd Lackovitch, Dave Parsons, and Jack Liles, released.]

Missile Detection and Targeting

The detection and destruction of incoming missiles have traditionally been a difficult technological challenge. Missiles are fast and relatively small, compared to aircraft, so it is more difficult to spot them and to pinpoint their exact location. In the United States, nonimaging infrared systems are used in a number of early warning systems. Infrared-sensor-equipped satellites, for example, have been established in conjunction with ground-based radar systems to warn of impending ballistic missile attacks.

In one U.S. missile defense test scenario, satellites provide the general guidelines for the vehicle launch (a nonexplosive projectile), radar systems aid in narrowing down the target missile, and infrared sensors help in homing in during the final seconds. The intercept vehicle is controlled through a computerized communications console, which is typically ground-based. If a hit is successful, the kinetic energy from the impact destroys the missile.



Traditionally, it has been difficult to track and destroy incoming missiles. Infrared sensors can aid in homing in on the projectiles during the final stages of the intercept. A continuous-wave deuterium fluoride chemical laser, known as a Mid-Infrared Advanced Chemical Laser (MIRACL), is used to destroy a short-range rocket in flight (left) at the U.S. Army Space and Strategic Command's High Energy Laser Systems Test Facility, as part of the Nautilus program. The test indicates that lasers may be effective in combating hostile incoming airborne projectiles. [U.S. DoD 1996 news photos, released.]

The U.S. Boost Surveillance and Tracking System (BSTS) was initiated in 1984 as part of the Ballistic Missile Defense (BMD) program. BSTS was designed to replace aging systems which had been providing space-based infrared data since the early 1970s. The BSTS was the first tier of the BMD system. It was transferred to the Air Force as the Follow-on Early Warning System (FEWS) which evolved into the Alert, Locate, and Report Missiles program.

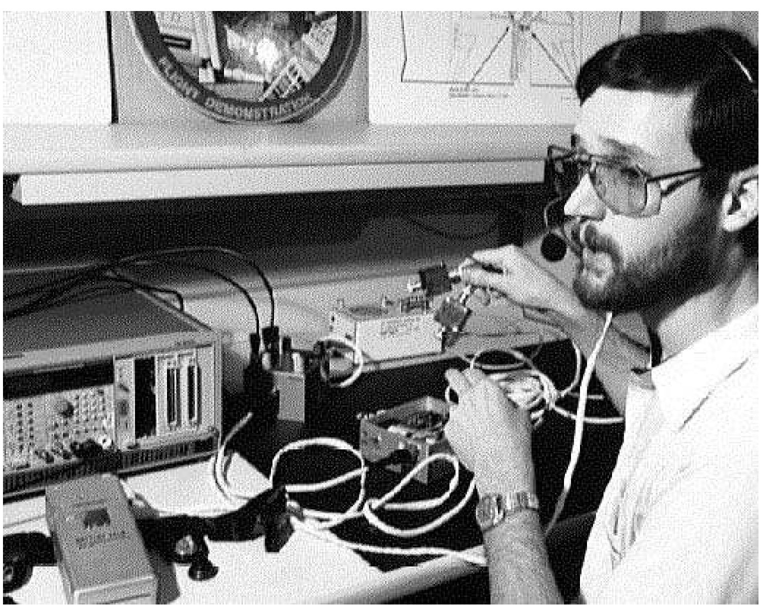
The U.S. also established a space-based infrared system in low-Earth orbit (LEO) called the Space and Missile Tracking System (SMTS), the second tier of the BMD system. This passive-sensor system performs ballistic missile boost and post-boost phase acquisition and tracking. It also performs midcourse-phase tracking and discrimination in the NMD and TMD systems. SMTS evolved out of the Space Surveillance and Tracking System and the Ground-based Surveillance and Tracking System technology. Related experimental technologies include the Airborne Surveillance Testbed, Midcourse Space Experiment, and the Spatial Infrared Imaging Telescope series [O'Neill, 1995].

As an example of an infrared device, the U.S. Army midwave infrared missile seeker is mounted on a laser gyro-stabilized platform to isolate the seeker measurements from other vibrations. The seeker includes an all-reflective optical system and platinum silicide staring focal-plane array. The array serves as the optical sensor for the interceptor. Surveillance and fire control support are also provided by radar elements.

It has been reported that at least 15 nations have anti-ship missiles with infrared guidance systems. The Electronic Warfare Systems Group has been involved in an international collaborative research efforts to develop countermeasures to these infrared guidance systems. The Multiband Anti-ship Tactical Electronic System (MATES) for cruise missile defense was developed through this program. MATES was found to be capable of creating an optical breaklock (a jamming technique) in the missile's seeking mechanism at low power levels with more than 80% effectiveness in testing scenarios.

Remote Control and Communications Devices

Almost everyone with a TV, VCR, or stereo system has a portable remote control, most of which use infrared to allow the user to control power, channels, and various other settings from across a room. A remote control is a *line-of-site* device. That is, it won't work if there are infrared-blocking objects in the way, or if the controller isn't aimed in the general direction of the sensor (though sometimes you can bounce the signal off a reflecting surface). Remote-control devices work by sending pulses of invisible light that are picked up and interpreted by the sensor on the device being controlled. To visualize this more easily, imagine you and a friend are out in the dark, spaced about a block apart. Your friend uses a flashlight to send you instructions in Morse code. If a tree or house gets in the way, you don't get the message, and the light gets dimmer as you get farther apart. Infrared remote controls work much the same way, you just can't see the beam of light.



Joseph Prather is shown here with an infrared communications flight experiment (IRCFE) being readied for a flight on board the 1988 Space Shuttle Discovery STS-26 mission. The system uses light to communication in much the same way that radio waves are commonly used. [NASA/JSC news photo, released.]

Infrared can also be used for data communications systems. Think of your friend and the flashlight again, but imagine now that you both have flashlights, so you can send messages in both directions. Since it's pretty difficult to simultaneously interpret your friend's message and send one at the same time, you arrange a signal, called a *handshake*, that indicates that you are finished sending and now you will wait while your friend signals back (like saying 'Roger, go ahead,' on a handheld radio). By coordinating the signals, messages can be sent in both directions without causing confusion. Now imagine that the signals are sent with infrared data pulses rather than with flashlight Morse code pulses. This, in essence, is a wireless infrared communications device that, in turn, works very much like a radio-frequency wireless computer modem.

Motion Detectors

Security sensors commonly incorporate pyroelectric infrared (PIR) motion detectors into their systems. Typically, these are battery-operated so they can be placed in a variety of locations where electrical connections may not be available (carports, garages, worksheds, industrial yards, boat docks). These detectors are usually equipped with radio transmitters in the FM frequency which allow an alarm, recording device, or control console to be activated if the motion detector is triggered. Those which are operated on AC power may send the transmission through the electrical system, giving them a broader range, as in a large industrial complex or office building.

There are three measurements typically advertised with motion detectors:

range - the distance in which the detector is sensitive, usually about 20 to 40 feet

breadth - the angle within which the detector is sensitive, usually about a 70° to 80° radius

wavelength - the sensitivity range of the detector

Many motion detectors are designed with light sensors that act as a simple type of scheduler to activate the detector only in the dark (usually at night, or when a building is closed and the lights shut off). For 24-hour surveillance, this sensor can usually be defeated by putting a piece of tape over it, fooling it into thinking it's dark.

Many motion detectors are designed for indoor use and may not function optimally in temperature or moisture extremes. Recently there are more varieties available for indoor-outdoor use.

Since glass is opaque to infrared, it's not advisable to place a motion sensor behind a window of a door, for example, to detect someone approaching the door. Some of the infrared may reach the sensor, if it is near-infrared, but it may not be sufficient to trigger the sensor. It's best to place infrared sensors in a position where there are no impediments between the sensor and the area being sensed.

Infrared Sounders

Infrared sounders are used for atmospheric research and weather prediction. Sounders may be carried aboard satellites.

The National Oceanic and Atmospheric Administration (NOAA) uses infrared sounders to sense infrared emission sectra, including

HIRS - A High Resolution Infrared Sounder that has been in operation as a sensing instrument on a polar-orbiting satellite for two decades, providing data to the National Weather Service (NWS).

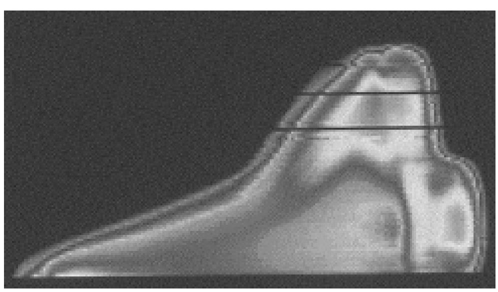
FIRS - A Fourier Transform Infrared Sounder that is a more recent than HIRS that uses a Bomem interferometer with a two-degree full-angle sensing field.

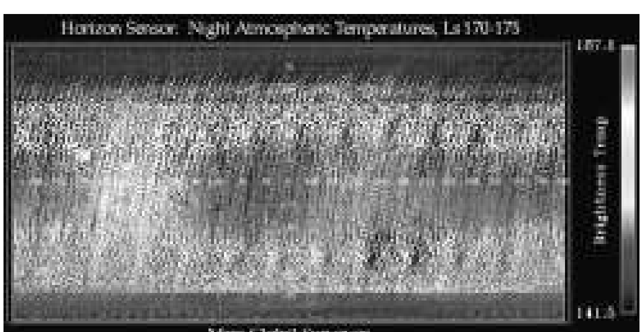
There are spectral regions in which the atmosphere can be quite opaque to infrared. While most sounders will sense in these obscured regions, scientists using the data are usually cautioned not to use data from regions known to be opaque.

Both NASA and NOAA use infrared sounders for weather prediction. It is important, in the space program, to carefully time the launch of various spacecraft to ensure safety and good operating conditions. The Atmospheric Infrared Sounder (AIRS) is a newer high-spectral-resolution infrared spectrometer. In conjunction with microwave sensors, AIRS provides weather prediction and environmental monitoring capabilities. Testing of AIRS began in the mid-1990s with plans to launch it on the EOS-PM spacecraft in 2000. AIRS has a higher spectral resolution than previous sounders and uses advanced computer processing to compensate for atmospheric and Earth emissivity and reflectivity effects.

Infrared Illumination and Thermal Imaging

One of the more straightforward and useful aspects of using infrared for surveillance is in archaeological research and forensic investigations. Infrared and ultraviolet light can sometimes reveal features that are not obvious under ordinary light. Shining infrared light through a document, bank note, drawing, or painting can sometimes yield surprises or important clues as to the composition or history of an item. For example, infrared investigation of a historical painting of John A. MacDonald, the first Prime Minister of Canada, revealed that a portrait of a woman had previously been painted on the canvas.





Top: This is an infrared image of a Space Shuttle on re-entry, showing the patterns of heat. The image was taken by the Kuiper Airborne Observatory (KAO) in 1982. The information on heat intensity and distribution is valuable for structural engineering and future shuttle design and also demonstrates the capabilities of the KAO infrared-sensing system. Bottom: This is an atmospheric temperature chart of Mars that shows thermal wave phenomena on the planet's surface, taken in 1999 on the Mars Global Surveyor mission. Temperature sensing and charting is a valuable implementation of infrared technology that can be applied to many fields of study. [NASA/Ames Research Center news photo, NASA/JPL news photo, released.]

Infrared thermal imagers are used for a number of industrial and inspection applications, including testing heat conduction and heat patterns, checking for cracks, determining weak spots or those subject to greater wear. They are also used for vehicle surveillance, tracking, and identification, especially in customs inspections and counterdrug operations.

Thermal imagers come in solid-mounted, portable, or headgear styles. The solid-mounted versions, if used on moving vehicles or aircraft, may include gimbal mechanisms to maintain spatial orientation.

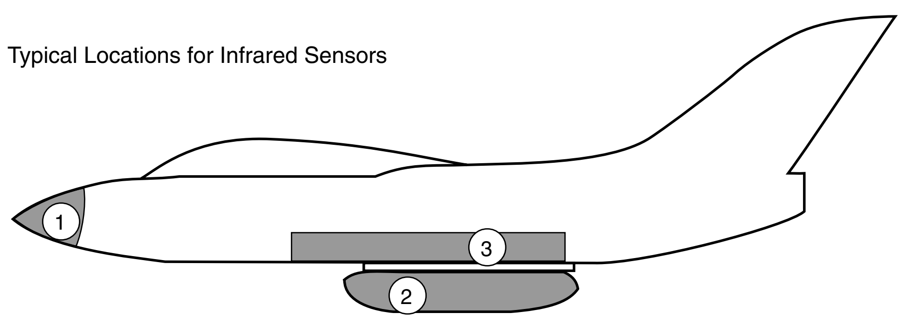
Thermal imaging systems are used not only in space science and industrial applications, they can also be used in novel ways to assess textiles and the relative thermal values of materials intended for hostile environments such as the cold arctic and antarctic regions. The Defence Research Establishment in Ottawa, Canada has created thermograms with a Dynarad fast-scan infrared camera to provide background information on experimental techniques for using thermal information to study clothing systems.

Bug Detectors

Some bug detection devices are equipped with standard or optional detection probes. In mid- and high-range detectors, there will often be an option for an infrared probe. These detectors range in price from $500 to $1,500.

Reconnaissance Aircraft (Piloted)

Reconnaissance aircraft are now routinely equipped with infrared sensors and infrared imaging systems, as are reconnaissance satellites, so there's only space for a few examples. Some additional examples are listed in the Aerial Surveillance chapter.



Reconnaissance-equipped aircraft most commonly carry infrared and radar equipment 1) in the nose, 2) in a fixed or detachable pod, and/or 3) internally in the belly of the craft.

The F/A-18 "Hornet" line includes a number of different models, some of which are equipped with Infrared Imaging Maverick Air-to-Ground missiles. The Hornet's night attack capabilities had been upgraded by 1989 including *navigation forward-looking infrared* (NAVFLIR) pod, night vision goggles, and special cockpit lighting for night vision devices, a digital color moving map and independent multipurpose color display. NAVFLIR is a fixed field-of-view sensor providing automatic electronic boresighting to optically align a scene on the pilot's HUD with the corresponding outside view. The second-stage upgrade was to add a FLIR pod with a built-in laser to designate targets for dropping laser-guided bombs (LGBs), cockpit modifications for night attack (night vision and lighting), and enhanced defensive countermeasures capabilities. However, in 1995, funding for upgrades were eliminated. The aircraft include targeting and navigation FLIRs.


Left: In-flight refueling between a U.S. Navy A-6E Intruder (left) and a French Navy Super Etendard. Right: Prior to decommissioning, the Navy A-6E Intruder receives its last launch signal from the deck of an aircraft carrier. The A-6Es use an imaging infrared seeker guidance system. [U.S. DoD 1996 news photos by Brent Phillips and Alan Warner, released.]

The F-14D "Tomcat," is equipped with a dual optical/electronics chin pod housing a *Television Camera System* (TCS) and the *Infrared Search and Track* (IRST) system. The aircraft has a passive infrared detection capability, targeting FLIR. Upgrades to the Tomcats include conversions from analog to digital and ATARS equipment with near-realtime traditional and infrared photos that can be transmitted to marine or ground stations.

Some of the F-14 Tomcat models have been equipped with the LANTIRN targeting systems and night vision systems. LANTIRN permits delivery of laser-guided strikes. The F-14D is equipped with the Infrared Search and Track (IRST) system. An F-18B is shown supporting the Iraqi no-fly zone in the Gulf. [U.S. DoD 1997 news photo by Bryan Fetter, released.]

The F-15E "Strike Eagle" is a long-range, all-weather, multimission strike fighter, equipped with navigation FLIR and targeting FLIR.

The F/A-18E/F "Super Hornet" was authorized by Congress in 1996, with assembly taking place in 1998. ATARS was installed in the nose of the test plane. The Super Hornet extended the Hornet's range, endurance, and survivability.

The *Low-Altitude Navigation and Targeting Infrared for Night* (LANTIRN) targeting pod system was developed in the late 1980s by Lockheed and installed in various F-15/F-16 models since 1988. As of 1995, the systems were being integrated into U.S. Navy F-14 'Tomcats' as part of the U.S. Navy's F-14 *Precision Strike Program.* These aircraft are intended for precision strike missions at low altitudes in darkness. The LANTIRN sensor uses a wide field-of-view FLIR system for target detection. On detection, it switches to a narrow field-of-view FLIR for target locking and weapons delivery.

Unpiloted Aerial Vehicles (UAVs)

One area of intense research and commercial interest is remote tactical reconnaissance vehicles. They have many advantages. They can be more quickly and easily replaced than conventional craft; the cost of manufacturing and operating them is tens of thousands of dollars compared to tens of millions of dollars for conventional aircraft. A further advantage is that there is no loss of life if the craft is shot down.

There are two basic types of UAVs, those which are remote-controlled, and those which are autonomous, operating through preprogrammed algorithms or self-modifying artificial intelligence software.

Early unpiloted aerial vehicles (UAVs) had limited range and endurance, but both capabilities have been substantially improved in recent years. Many UAVs are equipped with infrared-sensing equipment. Here are just a few examples of the many types of UAVs:

BQM-147A Exdrone - This is one of the earlier UAVs developed in the early 1980s at Johns Hopkins University. It has a delta-wing platform with an eight-foot span, weighing 40 to 80 lbs (depending on the payload). Its top speed was 100 MPH, with a datalink range of approximately 40 miles and an endurance of 2.5 hours. It sold for under $25,000. The Exdrone is manufactured by BAI Aerosystems and can be equipped with a variety of video and chemical sensors, and with forward-looking infrared (FLIR). At about the same time, the U.S. Department of Defense was initiating projects to design future ground-launched, multisensor UAVs with significantly greater range, endurance (up to 24 hours), and return capacity.

Global Hawk - A high-altitude, long-endurance aerial reconnaissance system rolled out by the Department of Defense early in 1997. It is capable of generating high-resolution, near-realtime imagery using synthetic-aperture radar (SAR) and electro-optical and infrared sensors.

General Atomics Aeronautical Systems Inc. (GA-ASI) - This company develops tactical endurance air vehicles, and their associated ground-station support. GA-ASI evolved their GNAT-750 (begun in the late 1980s) into the TE-UAV (Predator) which went into the test phase in the mid-1990s. These UAVs include FLIR along with video and line-of-site downlink capabilities. The GNAT-750 has an endurance of 40+ hours and can fly at altitudes of over 25,000 feet.

Predator - A Navy aerial reconnaissance craft capable of near-realtime infrared and color video sensing. Originally the Predator would beam reconnaissance information to a chase aircraft or a ground station, but it was upgraded to send signals over longer distances by relaying through satellites. These vessels have been used for training and Scud-missile spotting by the U.S. Army since the mid-1990s.

Tier III Minus DarkStar - A high-altitude, GPS-equipped endurance vehicle which can autonomously complete pre-programmed basic flight maneuvers and fly to an altitude of several thousand feet.

Hunter, Raptor, and Talon are similar vehicles used by the armed forces. Due to their size, cost, and flexibility, there is a possibility that UAVs may eventually supersede military fighter planes for many types of operations.

7. Problems and Limitations

Infrared sensors are not dangerous in the same way as X-ray emitters. Infrared radiation is everywhere and we have evolved to live in an infrared-rich environment. Most infrared sensing systems are passive systems, that is, they 'read' the infrared emanations without generating it first. Active infrared systems, like remote controls, are not typically hazardous.

Most of the limitations and problems associated with infrared sensing have to do with achieving higher frame rates and higher resolution images and with separating the target from the clutter. Also, as the technology becomes more precise, noise and interference become areas of concern. Here is a sampling of some of the technical limitations:

- The components used to build the detector have themselves thermal radiation that can interfere with the function of more sensitive detectors.
- As infrared wavelengths become longer, it becomes more 'expensive' to create detectors. Yet longer wavelengths yield good information for some applications (e.g., astronomy), as they can penetrate dust. From 100 µm to 350 µm there are few windows so broadband detectors, such as bolometers, are used in these regions.
- Semiconductor photocarrier decay times are important determinants in infrared detectors [Carr 1995]. Absorption in the far-infrared is frequency-dependent for many semiconductors due to photocarrier scattering rates.
- Medium- to long-wavelength technology is still expensive and short wavelength is still somewhat limited in capabilities.
- Stealth aircraft design may make a craft less visible on radar, but may still produce significant 'infrared signatures.'
- Nuclear and space radiation create noise spikes in infrared detectors (leading to false alarms) often necessitating expensive custom adjustments in each detector.
- Emissivity (thermal emittance relative to a black body) differences can provide misleading readings. For example, if a reflective surface has a less reflective covering (paint, cloth, etc.) and part of the covering is missing or scratched, false-positive 'hot spots' may show up in the image. Visual inspection of the material can help identify the source in some situations, and imaging from a number of angles can help identify whether the hot spot is on the surface, or behind it.
- Atmospheric clutter can impede infrared sensing intended to detect chemical and biological agents and aerosols.
- Film that is sensitive to infrared can photograph only reflected radiation in the near-infrared region. It isn't sensitive enough to spot a border-runner in the dark without supplementary illumination.
- Infrared films are subject to fogging and special handling and shouldn't be handled by technicians unfamiliar with infrared characteristics. Special filters generally need to be used, those transparent to infrared are opaque to human eyes, making it more difficult to compose an image.
- Infrared photos of the Earth from space dramatically illustrate how infrared can penetrate 'haze' and result in clearer, brighter images for many types of applications, but there are still limitations in infrared technologies in Earth-based applications. Infrared radiation has only a limited ability to penetrate fog or precipitation at certain wavelengths. Progress is being made in this area, however, by monitoring atmospheric properties and then using data processing to compensate for the interference.

8. Restrictions and Regulations

Unlike X-ray equipment, for example, there are very few specific restrictions and regulations for the use of infrared-sensing technologies beyond those more general considerations related to personal safety and privacy. There are health and safety regulations for the use of infrared in certain industrial environments (infrared is used for tasks such as drying printing inks), but these are typically active infrared systems, while a large proportion of surveillance technologies use passive infrared sensing, and thus are not subject to the same restrictions. Common sense is sufficient to deal with most infrared sensing technologies.

In fact, in many ways, infrared technology is subject to fewer restrictions than other technologies. For example, radio communications are very stringently regulated by the Federal Communications Commission due to the fact that radio waves can overpower each other and are in very heavy demand. Infrared has many applications in wireless communications and can even be used for wireless data communications on computer networks without most of the restrictions imposed on wireless networks based on the use of radio wave technologies. It should be remembered that infrared lies next to (and overlapping) the region designated as radio waves in the electromagnetic spectrum and far-infrared has certain properties in common with radio microwave radiation. Infrared is a good candidate for small, local, wireless, secured computer networks.

9. Implications of Use

Overall, infrared-sensing technologies tend to be used for applications such as fire detection, remote Earth and space sensing, telescopes, electrical fault location, home and office security, missile defense and general defense imaging. They are also used for remote-control and wireless intranet computer networks. Infrared technology is further used in medical applications, particularly for circulatory conditions.

Taken as a whole, infrared technologies have numerous personal and commercial benefits. Since the benefits of the technologies, as they are currently being used, seem to outweigh the negative aspects, there has not been a lot of controversy over the use of infrared in surveillance or other applications.

10. Resources

10.a. Organizations

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.

The Academy of Infrared Thermography (AIRT) - An independent educational institute dedicated to promoting and providing the highest standards of infrared instruction. http://www.infaredtraining.net/

American Institute of Aeronautics and Astronautics, Inc. (AIAA) - A nonprofit society serving the corporations and individuals in the aerospace profession to advance the arts, sciences, and technology related to aeronautics and astronautics. AIAA sponsors many technical meetings and conferences. http://www.aiaa.org/

CECOM - A U.S. Department of Defense mailing-list clearinghouse which automatically distributes IRIS conference proceedings to qualified subscribers. Subject to clearance by the Security Manager for the IRIA Center, this service can be requested through CECOM, Night Vision and Electronic Sensors Directorate, Security Branch, 10211 Burbeck Road, Suite 430, Ft. Belvoir, VA 22060-5806.

The Coblentz Society - A nonprofit organization founded in 1954 to promote the understanding and application of vibrational spectroscopy. It sponsors educational programs and awards in addition to providing member services. http://www.galactic.com/coblentz/index.htm

Electronic Development Laboratories (EDL) - Founded in 1943. Manufacturers of precision temperature measuring instruments and sensors including RTDs, thermistors, infrared, base metal and noble metal thermocouples, handheld pyrometers, solid state and infrared sensors. These products are especially useful in industrial settings for production line and quality control functions. http://www.edl-inc.com/ http://www.thermocouples.org/

FLIR Systems - A prominent commercial supplier of foward-looking infrared sensing products, including air, ground, thermographic and fire-fighting devices. FLIR sponsors the IR Info Symposium. http://www.flir.com/

Infrared Data Association (IrDA) - Founded in 1993 to support and promote software and hardware standards for wireless infrared communications links. http://www.irda.org/

Infrared Information Analysis Center (IRIA) - A service and product center sponsored by the Defense Technical Information Center (DTIC). IRIA was founded in 1954 to facilitate information exchange within the U.S. Department of Defense (DoD) to collect, process, analyze, and disseminate information on infrared technology and now also the entire electromagnetic spectrum. The IRIA Library houses over 50,000 items, including documents, proceedings, articles, and books. IRIA's classified and limited-distribution resources are available to qualified organizations meeting certain subscriber requirements. IRIA sponsors a number of special interest groups including infrared countermeasures, detectors, materials, and sensors groups. There is a broad range of information available at ERIM International Inc.'s site at http://www1.erim-int.com/

Infrared Space Observatory (ISO) - Launched November 1995 by the European Space Agency into an elliptical orbit to observe infrared radiation from 2.5 to 240 microns.

IRIA Target and Background Data Library (ITBDL) - Formerly the DARPA Infrared Data Library, established in 1978, this is now part of the Infrared Information Analysis Center (IRIA). Archival source of computer-compatible data tapes from DARPA-sponsored projects.

National Fire Protection Agency (NFPA) - The NFPA is an old organization, established in 1896, which promotes education and research, and scientifically based codes and standards for fire protection. http://www.nfpa.org/

Servo - Suppliers of thermal detection materials since 1946, particularly thermistor and pyroelectric detectors. Supplies primarily to the railroad and aerospace industries. http://www.servo.com/

SPIE - The International Society for Optical Engineering. SPIE has been at the forefront of optical research and development for many years and publishes many of the authoritative references on infrared technologies and their adaptation to aerial sensing and other detection technologies. http://www.spie.org/

Stratospheric Observatory for Infrared Astronomy (SOFIA) - A NASA/Ames Research Center project to create a nonorbiting facility with a large telescope flown in a 747 aircraft to get above most of the Earth's atmosphere. SOFIA will replace the Kuiper Airborne Observatory (KAO). This is just one of many NASA-related infrared projects. http://www.nasa.gov/

U.S. Air Force and FLIR Systems, Inc. - Involved in the cooperative development of a surveillance system called a Covert Adjustable Laser Illuminator (CALI) that uses a thermal imaging system to apprehend a ship's registration information in the dark. If pollution such as oil spills or covert flushing is detected or suspected, the CALI system can be used to identify vessels in the area and to record activity. Also suitable for ground surveillance and search and rescue.

10.b. Print Resources

Accetta, J. S.; Shumaker, D.L., editors, "Infrared and Electro-Optical Systems Handbook," IRIA and SPIE, 1996. Eight volumes with contributions by eighty infrared, electro-optical specialists.

Arnold, James R., "Space Science," California Space Institute, University of California, 1997. Chapters 9, 10, and 14 discuss infrared technologies, how they are used in space observation, and various limitations.

Avery, T. E.; Berlin, G. L., "Fundamentals of Remote Sensing and Airphoto Interpretation," New York: MacMillan, 1992.

Bass, Michael, Editor in Chief, "Handbook of Optics Volume I: Fundamentals, Techniques, & Design," New York: McGraw-Hill, Inc., 1995, ca. 100 pages. A multi-contributor, multi-volume comprehensive coverage of the topic, with Volume II also of interest. Extensive contributions by specialists in the field.

Beam, Walter R., "Command, Control, and Communications Systems," New York: McGraw-Hill Publishing Company, 1989, 339 pages. Practices and techniques for designing, developing, and managing CCC (C-cubed) systems.

Caniou, Joseph, "Passive Infrared Detection: Theory and Applications," Boston: Kluwer Academic Publishers, 1999. The basic physical principles and how they related to infrared detection technologies. Suitable as a reference text for students, technicians, physicists, and engineers.

Cindrich, Ivan; Del Grande, Nancy K., "Aerial Surveillance Sensing Including Obscured and Underground Object Detection," SPIE, April 1994 Conference Proceedings, 1994. There are dozens of SPIE conference proceedings (too many to list here) of direct relevance to infrared technologies used in surveillance activities directed at high undergraduate/graduate-level readers. Contact your local library for a full list.

Curran, Paul J., "Principles of Remote Sensing," London & New York: Longman Group Ltd., 1985.

Dennis, P. N. J., "Photodetectors: An Introduction to Current Technology," New York: Plenum Press, 1986, 176 pages.

Dereniak, Eustace L.; Boreman, Glenn, "Infrared Detectors and Systems," Wiley Series in Pure and Applied Optics, John Wiley & Sons, 1996, 561 pages. Written by a specialist in optical detection who has designed systems for Rockwell and Raytheon, Ereniak is a professor at the Optical Sciences Center at the University of Arizona.

Driggers, Ronald G.; Cox, Paul; Edwards, Timothy, "Introduction to Infrared and Electro-Optical Systems," Boston: Artech House Optoelectronics Library, 1999. Comprehensive introduction to the analysis and design of infrared and electro-optical imaging systems and systems analysis, including linear shift-invariant (LSI) infrared.

Fellowes, P. F. M.; Blacker, L. V. Stewart; Etherton, P. T.; The Marquess of Douglas and Clydesdale, "First Over Everest,"John Lane the Bodley Head Limited: London, 1933, 279 pages. A 1933 team of aerial photography pioneers describes the remarkable 'state-of-the-art' adaptations and inventions that allowed them to take the first aerial photos of Mt. Everest and the closed region of the Himalayas and Nepal in both traditional and infrared modes. The authors provide illustrations and make recommendations for future similar missions.

Feynman, Richard P., "QED: The Strange Theory of Light and Matter," Princeton University Press, 1985, 158 pages. Feynman, a Nobel laureate and Caltech instructor, created this introductory series of lectures containing some challenging but fundamental concepts in the behavior and study of photons and electrons within the framework of quantum dynamics.

"Handbook of Kodak Photographic Filters," Eastman Kodak Co., Publication B-3, revised 1990. Lists information on filters suitable for infrared (and ultraviolet) photography.

Holz, Robert K., Editor, "The Surveillant Science: Remote Sensing of the Environment," Houghton Mifflin, 1973, 390 pages. Though an older volume, this is a good selection of articles by remote-sensing specialists which starts with simpler, more basic concepts and takes the reader through the evolution to practical, applied sensing.

Hudson, Jr., Richard D., "Infrared System Engineering (Pure and Applied Optics)," New York: John Wiley & Sons, 1969, 642 pages.

Hudson, Jr., Richard D.; Wordsworth Hudson, Jacqueline, editors, “Infrared Detectors,” Stroudsburg, Pa.: Dowden, Hutchinson & Ross, 1975, 392 pages.

Iannini, Robert E., “Build Your Own Working Fiberoptic Infrared and Laser Space-Age Projects,” Tab Books, 1987, 262 pages. If you are a hobbyist who prefers to learn by hands-on methods, this book provides a project-by-project format that can help the reader get an introductory working understanding of some basic infrared technology.

Jacobs, Pieter A., “Thermal Infrared Characterization of Ground Targets and Backgrounds (Tutorial Texts in Optical Engineering),” Bellingham: SPIE, 1996, 220 pages. Introduction to heat transfer, target detection, atmospheric considerations, infrared signatures, and camouflage.

Klein, Lawrence A., “Millimeter-Wave and Infrared Multisensor Design and Signal Processing,” Artech House, 1997, 520 pages. A practical introduction to principles and applications including passive and active technologies, optics, detector theory, weapons sensors, Earth resource and weather monitoring, and traffic management.

Kodak staff, “Infrared and Ultraviolet Photography,” Kodak, 1961.

LaRocca, A. J.; Sattinger, I. J., Editors, “An IRIA Annotated Bibliography: Proceedings of the Infrared Information Symposia (IRIS)(1984-1991),” November 1991, ERIM Report No. 213400-118-X, 500 pages. Includes almost 2500 technical papers for the years 1984 to 1991 on a variety of topics including infrared systems for reconnaissance, surveillance, navigation, weapons guidance, countermeasures, and fire control. Available to qualified organizations.

Lloyd, J. M., “Thermal Imaging Systems,” New York: Plenum Press, 1975, 456 pages.

Lo, C. P., “Applied Remote Sensing,” Harlow, Essex, U.K.: Longman’s Scientific & Technical, 1986.

McLean, Ian S., Editor, “Infrared Astronomy with Arrays: the Next Generation,” Boston: Kluwer Academic, 1994, 572 pages.

Morey, B.; Ellis, K.; Perry, D; Gleichman, K., “IRIA State of the Art Report: Infrared Signature Simulation of Military Targets,” September 1994, Unclassified, ERIM Report No. 246890-2-F.

Nielsen, H. H.; Oetjen, R. A., “Infrared Spectroscopy from W. G. Berl's Physical Methods in Chemical Analysis - Volume 1,” New York: Academic Press, 1950.

Paduano, Joseph, “The Art of Infrared Photography,” Amherst Media, 1998, 112 pages. Descriptions of the different aspects of infrared photography, darkroom information, the use of filters, exposure settings, and flash and examples of infrared images.

Proceedings of the Society of Photo-Optical Instrumentation Engineers, Esther Krikorian, Editor, “Infrared Image Sensor Technology,” SPIE, 1980, Volume 225, 163 pages.

Proceedings SPIE–The International Society for Optical Engineering, “Airborne Reconnaissance XVIII,” Bellingham: SPIE, 1994, 276 pages.

Rogalski, Atoni; Kimata, Masafumi; Kocherov, Vasily F.; Piotrowsi, Jo, “Infrared Photon Detectors,” Bellingham: SPIE, 1997, 658 pages.

Ruttledge, Hugh, “Everest 1933,” Hodder & Stoughton: London, 1934, 390 pages.

Vincent, John David, “Fundamentals of Infrared Detector Operation and Testing,” John Wiley & Sons, 1990, 504 pages. Comprehensive operation and testing reference with formulas and examples for laboratory applications. Includes detector types, radiometry, measurement and more.

White, Laurie, “Infrared Photography Handbook,” Amherst Media, 1996, 108 pages. Covers photography and spectral information, particularly with regard to Kodak HIE (black and white) film. Provides guidance in getting started in infrared photography with many examples.

Wolfe, William L.; Zissis, G. J., “The Infrared Handbook,” Washington, D. C.: IRIA, Dept. of the Navy, 1985, 1700 pages. A large, classic reference work.

Wolfe, William L., “Introduction to Infrared System Design (Tutorial Texts in Optical Engineering),” Bellingham: SPIE, 1996, 131 pages. Course notes related to detection, scanning, optics, and radiometric aspects of infrared technology.

Workman, Jerry, editor; Springsteen, Art W., "Applied Spectroscopy: A Compact Reference for Practitioners," Academic Press, 1998, 359 pages. Practical guidance in ultraviolet, visible, and infrared reflectance spectroscopy covering various topic areas.

Articles

Aumann, H. H., "Atmospheric Infrared Sounder on the Earth Observing System," Paris, France, *ASAP, Sensors, Systems and Next Generation*, available from the JPL Technical Report Server.

Bissonnette, L. R.; Roya, G.; Theriault, J-M., "Lidar Monitoring of Infrared Target Detection Ranges Through Adverse Weather," *Canadian Department of National Defence R&D Report*, 1998, 15 pages.

Bruce, Willam A., "Theoretical Model for Use of Infrared Detection for Host Location by the Bee-mite, Varroa Jacobsoni (Acari:Varroidae)," *Agricultural Research Service*, 1996. These parasitic mites may have sensors able to detect infrared light emitted by bees.

Carr, G. L., "Nanosecond Time-Resolved Far-Infrared Spectroscopy of Photocarrier Decay in GaAs," from a lecture at a meeting of the *American Physical Society*, March 1995.

Chevrette, P.; St-Germain, D.; Delisle, J.; Plante, R.; Fortin, J., "Wide Area Coverage Infrared Surveillance System (Infrared Eye)," *Canadian Department of National Defence R&D Report,* 1998, 36 pages. A new concept for improving infrared imaging systems and applied surveillance for search and rescue. Simulating the human eye, it allows surveillance and target acquisition in two fields of view simultaneously.

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Journals

"Astronomical Journal," American Astronomical Society professional journal in publication for over 150 years, published monthly.

"Astronomy and Astrophysics: A European Journal," professional journal published on behalf of the Board of Directors of the European Southern Observatory (ESO).

"The Astrophysical Journal," published by the University of Chicago Press for the American Astronomical Society, three times monthly, in publication since 1895.

"The Infrared Scanner Newsletter," published seasonally by Inframetrics. Includes back-issues to summer, 1995. Describes applications of the technologies, and new products related to infrared sensing. Some of the product brochures listed in the newsletter include article reprints from industry technical journals. http://www.inframetrics.com/newsletter/irscanner/

"Journal of Thermophysics and Heat Transfer," by the American Institute of Aeronautics and Astronautics.

"Journal of Optics A: Pure and Applied Optics," formerly Journal of Optics, it has been split into two publications. This journal of the European Optical Society covers modern and classical optics.

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.

"AIAA Aerospace Sciences Meeting and Exhibit," 39th American Institute of Aeronautics and Astronautics, Inc. conference, Reno, Nv., 8-11 Jan. 2001.

"Military Sensing Symposium Specialty Group on Infrared Detectors," military sensing symposium sponsored by the Infrared Information Analysis Center, Tysons Corner, Va., 5-7 Mar. 2000. Held in conjunction with the symposia on passive sensors, camouflage, concealment, and deception and infrared materials.

"AIAA Thermophysics Conference," 34th annual conference, in Denver, Co., 19-22 June 2000. http://www.aiaa.org/

"National Symposium on Sensor and Data Fusion," military sensing symposium sponsored by the Infrared Information Analysis Center, San Antonio, Tx., 20-22 June 2000.

"Symposium on Thermophysical Properties," 14th annual symposium in Boulder, Co., 25-30 June 2000.

"AIAA Guidance, Navigation, and Control Conference," Denver, Co., 14-17 Aug. 2000.

"InfraRed Information Exchange '98," a forum sponsored by The Academy of Infrared Thermography on all aspects of infrared thermography including research and applications. 25-27 Oct. 1998, San Diego, CA.

10.d. Online Sites

The Buffalo Project. An online version of a GISDATA paper on predicting urban temporal patterns by Batty and Howes. This well-illustrated site describes how remote sensing imagery can be used to predict urban change and growth. http://www.geog.buffalo.edu/Geo666/batty/strasbourg.html

fotoinfo.com. Has Web pages devoted to infared photography, including information on black and white negative and color slide infrared film, focusing, and processing. Surveillance uses are mentioned as well. http://www.fotoinfo.com/

Honeywell Infrared Projector Technology. This is a commercial site, focusing mainly on Honeywell Technology, but there are a number of well-illustrated product development descriptions in the Spotlight on Technology section that give an interesting account of some of the recent scientific and engineering inventions in the infrared field. The site is also searchable for other topics (e.g., ultraviolet). http://www.htc.honeywell.com/

Infra-Red Photography FAQ. A Frequently Asked Questions Web page gleaned from topics discussed on the USENET rec.photo group. This FAQ was compiled originally by Caroline Knight. http://www.mat.uc.pt/~rps/photos/FAQ_IR.html

Infrared, Inc. Suppliers of infrared cameras, software, and imaging systems. The site includes an introductory FAQ on infrared technology. http://www.infrared.com/

Infrared Spectroscopic Method. This is a good introduction to the use of Infrared Spectroscopy for identifying narcotic substances. It has a brief illustrated history, and a technical introduction to the science, followed by a good bibliography with some interesting historical references. It has been prepared by Charles Hubley of the Canadian Defence Research Chemical Laboratories and Leo Levi of the Canadian Food and Drug Laboratories.
http://193.81.61.210/adhoc/bulletin/1955/bulletin_1955-01-01_1_page005.html

Sierra Pacific Infrared Thermography. The site includes submissions from thermographers, papers on infrared technology, a glossary, and other resources of interest. http://www.x26.com/

Wireless Networks. This is good JTAP-sponsored introduction to wireless infrared networks by James Dearden, Canterbury Christ Church College. It discusses and diagrams wireless WANs and LANs, radio technology, and infrared LAN implementation.
http://www.jtap.ac.uk/reports/htm/jtap-014-1.html

Note: If you don't enjoy typing in long Web addresses (URLs), you can use the links set up on the author support page for this text. http://www.abiogenesis.com/surveil

10.e. Media Resources

"Through Animal Eyes," Dave Heeley, BBC-TV. 60 minutes, color. This show demonstrates how special video lenses and techniques allow viewers to imagine how various types of animals can see with senses beyond human senses. It illustrates the compound eyes of insects and crustaceans, an insect ability to perceive ultraviolet and the infrared heat-sensing pit organs of snakes.

11. Glossary

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

ABC — automatic brightness control. Since a bright light source can 'wash out' an image or in some cases, damage a viewing system's components (somewhat like a bright flashbulb aimed directly at your eyes in a dim room), ABC technology may be built into the infrared viewing system.

ACSS	ATARS common sensor suite
ADLP	ATARS DataLink Pod
AIES	Aerial Image Exploitation System. Ground-based center for processing of downlinked aerial imagery.
albedo	the reflectivity of an object; the portion of incident radiation (as off a snowfield, or the surface of the moon)
ARO	Airborne Reconnaissance Office of the U.S. Department of Defense
ATARS	Advanced Tactical Air Reconnaissance System
ATD	advanced technology demonstration
ATR	automatic target recognition. A system of sensors designed to identify various types of craft, particularly those which may not cooperate in identifying themselves.
BLP	background-limited performance. A description of limitations related to signal-to-noise ratio of the target signal to the background radiation.
blooming	Spreading of brights spots in an infrared image, usually from light or heat sources such as headlights, fires, or anything else which contrasts brightly with its background. When the blooming is seen on printed images or photos, it is sometimes also called *bleed*. Some devices are designed to have cutoff-levels or other safety devices to prevent the type of uncomfortable temporary flash-bulb-like blinding that can occur in these circumstances and to protect the sensors from damage.
CCD	camouflage, concealment, and deception; charge coupled device
COMSEC	communications security [unit]
DARO	Defense Airborne Reconnaissance Office of the U.S. Department of Defense
DASA	Deutsches Aerospace includes the Military Aircraft Division which is involved in reconnaissance craft design as the prime contractor for the German Air Force Reconnaissance System.
DL	data link, data-link [capability]
DT&E	development, test, and evaluation
ECM	electronic countermeasure
EO	electro-optical
FLIR	forward-looking infrared. Often used in aircraft surveillance pods, which can be mounted on a gimbaled turret with 360° view, with about a 3 to 5 micron wavelength band. Provides terrain view at low altitude at night. When fitted with a 50 mm lens, the field-of-view (FOV) is about 14° horizontal by about 11° vertical [Jobe, 1994]. Spotlight coverage as opposed to IRLS realtime coverage.
FMC	forward-motion compensator/compensation. Compensatory system for resolving archetypes or anomalies resulting from the forward motion of an aircraft or ground vehicle carrying active image-sensing equipment. Some systems use mirrors for FMC.
FPA	focal-plane array
GRD	ground-resolved distance
IDS	imagery distribution system
IR/EO-LOROPS	Infrared/Electro-Optical Long-Range Oblique Photography System. A standoff, dual-band (visible and infrared), digital reconnaissance system designed primarily for use on F/A-18D reconnaissance aircraft, developed under the direction of the U.S. Navy. It is housed in a center-line station pod. Imaging is in the visible and medium-wave infrared spectral wavebands. Resolution capability in visible modes is about 2.5 to 4 feet at a range of 40 nautical miles; in infrared modes, it is about 2.9 ft at a slant range of 20 nautical miles. Imaging can be done at about 20,000 to

	40,000 feet altitude (for reference, common commercial airline carriers cruise at about 30,000 feet) at speeds ranging from mach 0.4 to 1.4. About 45 of digital data can be stored on tape, or transmitted to a ground station.
IRLS	infrared line scanner. 8 to 12 micron day/night instrument which vertically scans the ground, line by line, perpendicular to the flight path of an aircraft, creating a scrolling image. The speed of the IRLS is related to the altitude, scan angle, and the speed of the aircraft. Faster systems are needed to meet the needs of fast-flying tactical aircraft. The image can be frozen to allow scroll and zoom features to be used. Very useful for monitoring natural disasters and their after-effects.
IRP	infrared projector, infrared processor
IRPU	infrared processing unit
IRST	infrared search and track system
ISU	imaging sensor unit
JSIPS	Joint Service Image Processing System
LANTIRN	Low-Altitude Navigation and Targeting Infrared for Night
LPI	low probability of intercept
MAE UAV	medium-altitude endurance unstaffed/unmanned air vehicle
MFD	multifunction display
MMSA	multisensor, multimission surveillance aircraft
NCID	non-cooperative identification
NDIR	nondispersive infrared
NDT&E	non-destructive testing and evaluation
NIRS	near-infrared reflectance spectroscopy
NOLO	no live operator - autonomous or remotely controlled vehicles and systems
PIRA	Photo and Infrared Resolution Range. Part of the U.S. Air Force Flight Test Center at the Edward's Air Force Base.
QWIP	quantum-well infrared photodetector
RC	reconnaissance-capable
RMAPS	Reconnaissance Mission Planning Software. A Fairchild commercial software product.
RMS	reconnaissance management system
RSTA	reconnaissance, surveillance, and target acquisition
TADCS	Tactical Airborne Digital Camera System. An imaging system incorporating a Kodak digital camera with MicroLITE image distribution system which is used in airborne reconnaissance craft such as the F-14.
TARPS	Tactical Airborne Reconnaissance Pod System. Flown on the U.S. Navy F-14 Tomcat is a primary supplier of tactical photography. It was originally designed as an interim solution, but upgrades have extended its life into 2000 [Hancock, 1994].
TE UAV	tactical endurance unstaffed/unmanned vehicle
TID	tactical information display. A computerized system for displaying digital imaging data which may further be downlinked to a ground station. The TID can be used to assess imagery and make adjustments to the filters, exposures, or other camera parameters. Poor images can be reshot. Information can be overlaid prior to downlink or storage on disk. Usually used in conjunction with airborne, realtime and near-realtime reconnaissance imaging systems.
TOSS	Tactical Optical Surveillance System (U.S. Navy)
UAV	unstaffed/unmanned/unpiloted aerial vehicle