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INFRARED PHOTOGRAPHY

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Infrared photography is of interest to the amateur and commercial photographer and to scientists and technologists because it produces images that are not possible with conventional photographic films. In its practice there is not much difference between infrared and normal photography. The same cameras and light sources can usually be used, together with the same processing solutions. Infrared photography, however, is usually only attempted by skilled photographers, scientists, and technicians with a particular purpose in mind.

Technique

The peculiarities of infrared photography lie in the ability of the film to record what the eye cannot see (permitting, for instance, photography in the dark); in the fact that many materials reflect and transmit infrared radiation in a different manner than visible radiation (light); in the ability of infrared radiation to penetrate certain kinds of haze in the air so that photographs can be taken of distant objects that cannot be seen or photographed on normal films; and in the ability to photograph hot objects by the long-wavelength radiation that they emit. These properties permit infrared photography to be used as an important adjunct to photography by normal light.

The infrared range of the electromagnetic spectrum lies beyond the red. This portion of the spectrum is invisible to human eyes. Infrared includes all radiations between wavelengths just beyond those of the deepest reds of the visible spectrum (700 nm) and microwaves (100,000+ nm), which are used for cooking in microwave ovens. Although infrared covers a vast part of the spectrum, the portion of it that can be used to expose photographic emulsions is actually quite small (Figure 1). The area extends from about 700 nm to about 1200 nm, but most amateur and commercial infrared films are only sensitized to about 900 nm.

Photographs by infrared radiation were already made in the nineteenth century, but it was not until the early 1930's that it became possible to carry out infrared photography with the ease and certainty of ordinary photography. Just as orthochromatic and panchromatic films owe their response to the inclusion of certain sensitizing dyes, infrared-sensitive materials owe their response to special infrared dye sensitizers. The earlier infrared sensitive materials were quite low in speed, but with improvements in the methods of making photographic emulsions and the discovery of new dyes, it has been possible to make available for general use infrared films that are sufficiently sensitive that they can be used under average daylight conditions with unsophisticated cameras at fairly small apertures and reasonably fast shutter speeds, such as 1/125 second at f/11 for distant scenes to 1/30 second at f/11 for nearby subjects.

Infrared photographs are indispensable to astronomers, physicists and other scientists, and have permitted many important discoveries to be made. It was, in fact, with these applications in mind that most of the developments related to infrared films originated. The need to develop films for specialized scientific applications eventually resulted in the availability of infrared films that could be put to more practical uses in a large number of other applications and fields, from medicine and law enforcement to aerial photography, fine art, and many others.

The visible spectrum ends for all practical purposes at a wavelength of 700 nm, but films have been made, and are used by scientists, that respond to radiations up to about 1200 nm. Films that are used for general infrared photography, however, must have good speed, and in practice they respond up to about 900 nm.

Infrared-sensitive materials require the user to observe certain safeguards. Refrigeration is often advised during storage becasue the sensitizing dyes employed tend to be less stable than in other films, and exposed film should be processed promptly to prevent loss of image quality.

Since antihalation backing is not always added to infrared film, the images may be adverseley affected by halation.

In 35 mm cameras, film pressure plates sometimes impress an overall pattern of small dots of density on the film. This is caused by a regular pattern of dimples on the plate that focus the infrared energy that passes through the film back onto the film emulsion. This can be overcome by covering the pressure plate with a material with smooth finish and good infrared absorption.

Infrared Sources

The light sources commonly used in photography are also suitable for use with infrared materials. Most of them depend for their visible radiation on heating certain materials to incandescence, but a great part of their radiation is nevertheless in the invisible infrared region. The tungsten filaments in standard household incandescent lamps as well as in photoflood lamps and the foil or wire-filled flash lamps are especially suitable, since they have the peak of their emission in the part of the infrared where the films have their maximum sensitivity (Figure 2). A natural incandescent light source is the sun.

In addition to the sources that depend on the heating of materials, there are some that depend on an electric discharge through gases in a tube. There are many such sources, but some, like the fluorescent tubes used for room lighting, are not suitable for infrared work because they emit relatively little infrared energy. Electronic flash tubes, on the other hand, are usually very good sources of near-infrared energy and make good sources for infrared photography.

Unless one photographs a subject that emits only infrared radiation or is irradiated only with infrared radiation it is always necessary to use a filter, because all the infrared films are sensitive to light as well as to infrared. If no filter were used, the infrared effect would be largely masked by the exposure to light.

In typical photographic situations one would use a deep red filter such that when it is placed over a single-lens-reflex camera lens, the photographer can still see a dim image on the groundglass of the camera. More pronounced infrared effects may be obtained by using visually-opaque but infrared-transmitting filters. In this case, since it is impossible to view through them, it is common practice to fit the infrared filter to the lens of a rangefinder or a twin-lens-reflex camera. In single-lens-reflex cameras it may be possible to install visually-opaque filters just in front of the shutter but behind the mirror in order to retain the ability to compose the image on the groundglass. When photographing unobtrusively, in dimly lit situations or in the dark, the filter is placed over the light source instead of over the camera lens.

Equipment

Normal cameras can be used for infrared photography, but two possible sources of problems should be checked: (1) the camera body itself, bellows, film holders and dark slides, should be tested to ensure that they do not transmit infrared radiation and (2) the focus of the lens in the infrared region is usually different than it is for the visible spectrum. An adjustment needs to be made after the lens has been focused visually in order to achieve the best focus for the infrared images.

Since most lenses do not have their best focus for infrared radiation when they are focused for visible light, it is usually necessary to rack the lens forward slightly after achieving visual focus, as if focusing on a nearer object. The exact distance to give a sharp image can be determined by testing or by moving the distance focused upon visually opposite a special infrared focusing mark provided by the lens manufacturer on the focusing scale of some lenses. To some extent the focus problem can be minimized by using small apertures and relying on depth of field to take care of the discrepancy.

The camera and its attachments can be tested by loading film in the camera or in the film holder, exposing it to bright incandescent or sunlight illumination from all sides, and developing the film. Absence of fog indicates safety. The presence of fog means that the camera or other piece of equipment (it could even be the developing tank) is not suitable for use with infrared materials. Some of the newer plastic-body cameras should be carefully checked. Most commercially manufactured film holders have a mark placed on them if they are guaranteed to be safe for infrared use.

The instructions accompanying 35-mm Black-and-White infrared film warn the user that the film should be loaded into the camera in complete darkness, even though the cassette is a conventional daylight-loading type.

Standard developers may be used with infrared film but more vigorous development is usually recommended than for standard films. Fixing, washing and drying are the same as for normal photographic materials.

Lighting

Outdoor photography is done with the sun and skylight as the natural sources of infrared, and a filter is used over the camera lens to confine the exposure to the longer wavelengths. The normal rules for subject lighting are followed.

With artificial lighting in the studio, normal tungsten filament lamps, photoflood-type lamps, and electronic flash sources are all satisfactory. Front lighting is generally recommended when detail is desired.

Filters must be used on the lens, or, to make pictures "in the dark", on the light source. It should be noted that most polarizing filters are manufactured for use with visible radiation and that they will have very little, if any, effect on infrared rays. Special infrared polarizing filters are available. As in the case of all filters, those used over the lens must be chosen so that they will not impair the definition of the lens.

Exposure and Light Meters

Determining proper exposure of infrared is usually done on the basis of charts provided by the manufacturer since standard light meters are designed to measure light and not infrared. Further, standard photographic speed systems are based on exposing films to light and not infrared and therefore infrared film can not be assigned a conventional film speed index.

Most charts are based on the assumption that the ratio of infrared present in a light source and the amount of light emitted by the soure have some constant relationship. This essentially permits the assignment of a filter factor to the various filters that a photographer may use for infrared photography. It should be noted that the filter factors assigned for infrared film are smaller when tungsten illumination is used as opposed to daylight.

The application of filter factors based on exposure recommendations provided by reflected light meters may be in error because these meters are influenced by the color, tone or visual appearance of a given subject. Incident meters, on the other hand, may also indicate erroneous exposure compensation factors because they do not take the subject itself into account.

Photographers have calibrated meters whose cells approximately match the infrared sensitivity limit of the film by covering the meter cell with the same type of infrared filter that is used over the camera lens. These meters should always be used in the reflected mode to assure the photographer that a particular density will be achieved on the film. Since infrared tonal relationships are usually invisible, this ensures that infrared information is recorded, albeit possibly at an incorrect level of density.

Determining proper exposure for color infrared materials can be done with standard light meters as long as the photograph is not made striclty by infrared since two of the film's three color layers are sensitive to light. If the record is to be made by infrared alone it is usually best to use Black and White infrared film.

Infrared Fluorescence

Certain materials spontaneously emit infrared radiation when shorter visible radiation or ultraviolet radiation falls on them. This property, when taking place in the infrared, is sometimes called luminescence but is actually a special form of fluorescence, an effect more commonly seen when a subject emits light upon being exposed to ultraviolet radiation. In both situations the incident radiation is converted to longer wavelength radiation.

Usually two filters are required to accomplish infrared fluorescence photography. An exciter filter, typically a pale blue-green filter, is placed over the light source to limit the incident radiation to the shorter wavelengths of light. It is basically an infrared blocking filter. Its function is to prevent any infrared emitted by the source from reaching the subject. Some of the light falling on the subject is changed to longer, invisible infrared radiation. A second filter that only allows these newly formed rays to pass is placed over the camera lens. This filter is called a barrier filter. It is usually a visually opaque infrared filter. Its function is to block all visible rays with which the subject is illuminated from reaching the film.

The exciter filter can be omitted if the incident radiation can be limited to visible wavelengths by using a source that emits only wavelengths shorter that infrared ones. Wavelength tunable lasers provide such a source and they have the added advantage of being able to easily select from a wide range of wavelengths for exciting fluorescence in the infrared or other areas of the spectrum.

Applications

For many years, the popular conception of infrared photography was that it was a way of seeing through fog. This was largely the result of the sensational handling of the subject by the press. In fact, infrared photography does not provide a way of seeing through fog, which consists of water droplets, although it can improve visibility through certain kinds of haze where the light scattering is produced by much smaller particles.

Long-distance Photography

This property is particularly important for long-distance photography on the ground where the detail of distant objects is often obscured by haze, and for high altitude, and especially oblique photography from the air. Actually, infrared photography does not always result in a very marked increase in the range of vision, but it generally increases the contrast of the distant subjects and thus the amount of detail that can be seen. This produces the effect of greater penetration.

For long distance infrared photography, the modern fast infrared film is used with a red filter equivalent to a Wratten #25 or tricolor red. Along with improved detail in distant subjects, the general effect is one of an abnormal rendering of subject colors. Grass and leaves of deciduous trees appear white, as if covered with snow, although the coniferous trees generally appear dark. Clear sky is reproduced very dark, particularly away from the horizon and away from the sun. Clouds appear white and, in the case of heavy cumulus clouds, they stand out strikingly against the dark sky. High, wispy clouds, which may be invisible in an ordinary photograph, may show up clearly. Water generally appears black, unless it is turbid with suspended matter.

Portraiture

Infrared protraits, outdoors or indoors, appear unusual because infrared radiation causes skin to have a chalky appearance, red lips to appear very pale, and eyes to appear as dark spots. Doctors, however, use infrared photographs for diagnostic purposes. Infrared radiation tends to penetrate turbid skin and show up the veins lying close to the surface, and from their appearance certain medical conclusions can be drawn.

Survey and Reconnaissance

In infrared photographs made outdoors from the ground or from the air, grasses and the foliage of deciduous trees appear white because of the high near-infrared transmission characteristic of green chlorophyll and the high infrared reflectance of the underlying cellulosic structure of these subjects. The result is that the infrared contrast of a landscape or an aerial terrain may be quite different from the visual contrast, and this, over and above enhanced penetration resulting from use of the longer wavelengths, may help to increase visibility of distant objects. Further, it helps in aerial survey and reconnaissance to distinguish deciduous trees and grass from coniferous, diseased and dead trees and burned grass, which tend to appear dark in an infrared photograph.

There is a common misconception that infrared is used as a means of camouflage detection in wartime. While this may have been the case in the early days of infrared photography, the application of infrared for this purpose is no longer generally practiced. On the other hand, it is possible to distinguish living plants and foliage from green paints if no special precautions are taken with the paint. Most normal green paints, which match green foliage visually, are strong absorbers in the infrared and appear dark in an infrared picture, while natural green foliage photographs as white.

In practice, infrared photography has been used in forest survey to distinguish between stands of coniferous and deciduous trees. It is also possible to detect the presence of disease in plants and pollution in rivers and other bodies of water.

An important application of infrared aerial photography in war is its use for determining depth of water and detecting underwater obstacles off potential landing places on enemy coastlines. It has been claimed that by comparing infrared and conventional photographs of average coastal waters, depths to 20 feet can be determined to an accuracy of 10 percent. Infrared photographs have been used for the construction of charts, the study of sandbars and silting of navigable channels, the control of erosion and pollution, the charting of currents, and the study of marine life. Seaweed surveys have also been made by infrared photography.

In the Dark

Since infrared radiation is invisible, photography in total darkness can be readily carried out if infrared film is used and the light source is covered with a light-absorbing but infrared-transmitting filter.

Infrared flash photography has been used in this way for many special purposes, such as press photography outdoors in the blackout during war, for photographing during nighttime landing operations on an aircraft carrier and in other situations where a bright flash would be disturbing (or betray the photographer), such as for detection of intruders and criminals in the dark; audience-reaction studies in lectures, training-film projection, and motion-picture theaters; unobtrusive instrument recording in aircraft; dark adaptation studies of the eye; photography of wildlife in darkness; and photography of industrial operations that are carried out in the dark, as in the photographic industry.

Usually, filters that permit the passage of the minimum of visible radiation are used but it must be recognized that deep red light can be very visible in the dark. The filters may be placed over the front of the flash unit, or the flash bulb or the jackets of electronic discharge tubes may be dipped in a dark, infrared-transmitting lacquer. Normal safelight lamps provide a good lamphouse if an infrared filter is used in place of the safelight glass. Suitably dyed plastic bags have also been used as covers for flash bulbs.

In audience-reaction studies by flash, it is usually sufficient to cover flash lamps and reflectors with an infrared filter, and point them to the ceiling as for bounce-flash to produce illumination that is invisible to the audience. Members of the audience who are looking in the direction of a flash unit covered with a deep infrared filter, will probably be conscious of a red flash. A few deep ruby bulbs among the cove lights or in the exit signs of rooms can often provide enough unobtrusive illumination for infrared photography.

Document Inspection

Infrared photography, particularly infrared fluorescence photography, has found several applications in criminological investigations, and it is a standard tool in many laboratories for the study of faded, burned, worn, dirty or altered documents; the differentiation between pigments, dyes and inks which may appear indistinguishable to the eye; examination and identification of cloth, fibers and hair; detection of secret writing, and a variety of other special applications.

In the study of documents, infrared photography was dramatically used in the early thirties for showing up printing underlying the obliterating ink of censors which, although black to the eye, happened to be transparent to infrared. In this respect, infrared photography is an important adjunct to ultraviolet photography in document examination. Printed matter, engravings and photographs that have become undecipherable through dirt or age can frequently be revealed. Mechanical or chemical erasure can often be determined, even if overwritten, provided, of course, the overwriting is in an ink transparent to infrared, and even writing on documents charred in fires has been made readable provided the charring has not gone too far. Infrared photography has taken a place with chemical, ultraviolet and X-ray study in determining the authenticity of works of art.

Scientific and Industrial

Infrared photography is one of the accepted tools of the applied photographer, and the imaginative worker should have little difficulty in recognizing its possibilities and enlarging its field. Among the special uses, mention can be made of: plant pathology, in the study of plant diseases where there is change in pigment or cellular material; paleobotany, particularly in coal petrology; in the textile field for detection of irregularities to the fibers, particularly where the material is dyed a dark tone and visual examination is difficult; in photomicrography of deeply pigmented tissues and thick sections, to show enhanced details of internal structure; and in the study of furnaces while they are operating.

Since heated objects emit infrared radiation, in some circumstances they may be photographed on infrared films by the infrared rays they themselves emit. The surface temperatures of hot objects such as hot plates, engine parts, stoves, cooling ingots and castings, have been studied in this way. The useful range is limited, however, because at temperatures below about 400 degrees Celsius exposure times become impractically long.

Infrared photography is a tool of great importance in astronomy and spectrography. Through its means, hundreds of new lines have been recorded in the spectra of the elements, much has been recorded in the spectra of the elements, much has been learned of the composition of the stars and the atmospheres of the planets, new stars have been discovered and the haze of nebulae has been penetrated to bring us a fuller knowledge of the universe.

While direct infrared photography is limited to a maximum wavelength of about 1200 nm, the recording of longer wave radiations is possible by certain other methods. For instance, the latent photographic image can be partially destroyed by long- wave red and infrared radiation (the Herschel effect) with photographic emulsions that are otherwise not sensitive to red light. This effect has been used to make direct-positive copies of documents by making prints on fogged bromide paper using long- wavelength radiation for the image exposure.

Color Infrared Photography

Multilayer color films are also available and used in which one layer responds mostly to blue and infrared while the other two respond to green and blue, and red and blue, respectively (Figure 3). This film is designed for use with a yellow filter that eliminates from a scene the blue light to which all layers are sensitive. The film will reproduce a neutral as neutral when it reflects approximately equal amounts red, green and infrared radiation. Other colors assume a distorted character and a false- color, color picture is produced in which everything shows up with an abnormal color (Figure 4). The yellow-dye layer responds to green light, the magenta-dye layer to red light and the cyan- dye layer to infrared radiation.

Thus it is possible to identify areas where there is a little or much infrared present by the amount of cyan dye formed in the film. In addition, since the other dye layers are not complementary to the colors that they respond to, most colors in the final transparency generally bear little resemblance to the colors of the original scene. This can be used to aesthetic advantage as well as to make the differentiation between subjects of similar color or tone more obvious. The method is particularly applicable when the objective is to detect small differences in the infrared reflectance of visually similar subjects.

Assuming that the subject is yellow and reflects approximately equal amounts of red and green, exposure to yellow alone will produce similar amounts of magenta and yellow dye in the film giving the appearance of red for these two layers only. If, in addition, the subject is made up of a lot of infrared radiation exposure to infrared will not produce much dye in the cyan layer and the subject will look very red. On the other hand, if the subject contains little infrared, the cyan layer will be unexposed and full cyan density will remain in the film making the subject appear cyanish. A similar approach can be taken to predict other colors that the film will produce under specific conditions.

The film has widespread applications in military aerial photography, remote sensing, and environmental impact studies. At one time standard color films and infrared films could be processed in the same solutions, but current color infrared emulsions require solution formulations that are not the same as those used for most other coupler-incorporated emulsions.

Infrared Image Converters

Special devices are available that convert infrared radiation to light. The most common of these is the image converter. The infrared radiation collected by a lens is focused on an electrically charged surface called a photocathode. The infrared radiation causes electrons to leave the photocathode and these electrons are focused by a magnetic lens on a screen coated with a fluorescing material. In this fashion the invisible infrared image formed on the photocathode surface is made visible as a fluorescent image that can be seen or recorded with a camera loaded with conventional film.

Infrared image converters are used in photofinishing laboratories and photosensitive materials manufacturing plants to monitor procedures that do not involve handling infrared sensitive products. They also are used to gain a visual appreciation of the infrared appearance of a subject prior to photography with infrared film.

Thermography

While normal infrared photographic techniques use radiation reflected from the subject to form images, thermography utilizes infrared radiation naturally emitted by objects at all temperatures above absolute zero. Further, it works with infrared receptors other than photographic emulsions, such as certain types of photoelectric and transistor cells. Thermography extends the sensitivity range to wavelengths of approximately 10,000 nm and is suitable even for recording heat radiations emitted by objects at 0 degrees Celsius.

A thermographic recording camera, which includes a lens and moving mirrors or prisms that scan the image, focuses the heat rays on an infrared detector. The scan moves over the subject area in a television-like pattern (Figure 5).

Radiation from successive small scanned areas is converted into electric signals that are amplified and used to modulate an electron beam scanned over the surface of a cathode ray tube (CRT) in synchronization with the movements of the scanning system in the camera. In this fashion a television-like picture is seen on the CRT in real time. A thermogram is made by simply photographing the image on the CRT tube.

Applications of such thermographic scanning techniques include the detection of heat loss in buildings, the analysis of military targets and backgrounds (the presence of vehicles on the ground can, for instance, be detected by the higher temperature of their engines), monitoring industrial process installations, testing heating and cooling systems, investigating the degree of heating up of engines, electrical components and other machinery in use, as well as medical and biological investigations. In the last case slight variations in the skin temperature of a subject may reveal hidden tumors and other clinical conditions.