Chapter VI

Examination by Infrared Radiation

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1. Introduction

Infrared radiation — an invisible part of the electromagnetic spectrum — can and has been used in the scientific and technical examination of works of art. The results can be useful in art history and conservation.

The radiation used must be translated by the imaging device into visible radiation. This can be accomplished only to a very limited degree by certain photographic emulsions. Generally special infrared-to-visible image translation systems are required. Those which have been used in the scientific examination of works of art are usually either simultaneous read-in and simultaneous read-out devices such as image converters or have sequential read-in and read-out. The instruments used in infrared reflectography are of this latter class.

Although examination with infrared radiation can be quite helpful in conservation — revealing damaged areas in a way complementary to other methods of surface examination such as X-radiography and ultraviolet fluorescence — it has been most effectively and promisingly applied to the detection of underdrawings. Increased and systematic use of especially infrared reflectography for elucidating art historical problems has resulted in encouraging and often spectacular results by revealing previously invisible manifestations of graphic art.

2. Infrared photography

Ordinary photographic emulsions consisting of silver halides deposited in granular form within a gelatin do not normally respond to invisible infrared radiation. H.W. Vogel discovered in 1873 that the spectral response of silver halide emulsions could be extended by adding certain dyes.

Infrared photography is also a simultaneous read-in, simultaneous read-out process using such film which has been made responsive beyond the visible red[1].

The visible radiation is prevented from blackening the film by placing a cut-on filter in front of the lens which eliminates radiation with a wavelength smaller than c. 7000 Å.

2.1. *Films*

In theory films are commercially available with a wavelength response up to c. 11.000 Å. There is a physical limit to a realistic wavelength for film material due to the fact that the film is also responsive to radiation emitted by the surroundings such as the envelope which would fog the film if not cooled. All infrared films have therefore to be stored at —18 to —23 °C and used 6-8 hours after being taken out of the refrigerator[2].

Proper handling of infrared sensitive films implies further that the films are loaded in complete darkness. A correction for the longer wavelength must be made in focussing properly. Photographic lenses are calculated for the visible region of the spectrum, but most better lenses have an infrared focus mark to correct the normal focussing when using infrared film responsive up to 9000 Å. The resulting visual focus should be shifted to the infrared focus position. The focus distance can alternatively be increased away from the subject by 0.25 %.

Stopping down to small apertures is recommended wherever possible for obtaining sharp infrared photographs but this may lead to long exposures. For optimum results at least 4 × 5 inch sheets should be used with a professional camera. Sheet material is not always easy to obtain commercially in smaller quantities.

Kodak has hypersensitized spectroscopic plates on the market with a wavelength response up to 9000 Å (I en N), 10.000 Å (I en M) and 11.600 Å (I en Z)[3]. Such plates when used to photograph details of paintings provide good resolution.

The readily available Kodak High Speed Infrared film 2481 is responsive up to c. 9000 Å but has only medium resolving power (80 lines per mm). The moderately coarse grain in the film can become quite disturbing when larger areas are photographed.

2.2. *Filters and lenses*

For most infrared films sensitive to radiation with a wavelength up to c. 9000 Å a filter cutting-on at 7000 Å is satisfactory. Kodak Wratten filters 87 or 87 C are usually recommended. With High Speed Infrared films and halogen lamps the exposure time can be in the order of seconds. Less sensitive infrared film requires up to half an hour exposure time.

The transmission in the near infrared of the lenses used should be checked with a spectrophotometer. Although glass transmits up to 2.8 microns the various coatings used in modern lenses could impair the transmission in the near infrared. Such a check is even more imperative in infrared reflectography (vide infra).

2.3. *Illumination*

In infrared photography tungsten filament lamps with clear glass envelopes can be used conveniently. Clear glass is to be preferred as the phosphorous coatings on the inside of the matted glass bulbs may impede infrared transmission.

Quartz lamps such as are used in floodlights for filming are also convenient. They can be ventilated to eliminate heat transfer by convection.

The output of some flash units contains sufficient radiation in the photographic infrared but this should be checked by comparing with exposures using illumination by tungsten lamps. There is no point in placing infrared filters in front of the illuminating sources. This is a purely military requirement where the observer at night wants to remain unseen.

2.4. *Processing*

Processing of infrared films should be carried out according to the manufacturer's instructions and in total darkness. No safelight can be used in the darkroom which should be carefully made tight against near infrared radiation.

The contrast of the 35 mm High Speed Infrared film is usually poor. This should be compensated for in the developing process. In printing infrared film negatives certain areas can be emphasized or prevented from being too dark by both dodging and masking techniques[4].

Loose[5] and Nickel[6] obtained improved contrast and readability of underdrawings by using special masking techniques. Correct tone rendering is not always achieved, however. Teixeira[7], used translucent paper to distinguish better half-tone details.

Van de Voorde used an improved compensation method of printing high-contrast negatives also with infrared film[8].

2.5. *Applications of infrared photography*

Infrared photography has been used in the study of graphic documents, ceramics and most of all paintings[9]. In the restoration studio infrared photographs have been used to study the condition of paintings and occasionally for better revealing signatures.

Art historians used infrared photography for studying partially visible underdrawings.

Desneux[10] has discussed underdrawing visible in infrared photographs of a number of Van Eyck paintings.

Taubert[11] has compared infrared photographs of paintings by Van Eyck, Dirk Bouts and Memling. His description of characteristic aspects of underdrawing in these three groups has been confirmed by later work with infrared reflectography. Taubert also showed the importance of underdrawings in the study of copies and workshop traditions[12].

Lavalleye[13] used infrared photographs to discuss the Joos van Gent-Pedro Berruguete problem. Van Schoute has employed infrared photographs in studying panels in the Granada Capilla Real[14] and in paintings attributed to Dirk Bouts[15], Hugo van der Goes[16], Hieronymus Bosch[17] and Pieter Brueghel[18].

Arndt[19] has used infrared photographs in a paper on a panel by Gerard David. The 'Centre national de recherches *Primitifs flamands*' in Brussels has regularly made use of infrared photographs in their 'Corpus des Primitifs flamands'.

German and Austrian painting has occasionally been studied with the use of infrared photographs[20].

Sonkes[21] has systematically used available infrared photographs in an attempt to describe the underdrawing on paintings in the group Van der Weyden/Master of Flémalle.

More recent contributions often use both infrared photographs and infrared reflectograms. Van Schoute and Hollanders-Favart[22] have published a bibliography on such publications covering the period 1975-78.

2.6. *Limitations*

Underdrawings can frequently be revealed by infrared photography when present beneath reddish, brownish and whitish areas. Green and blue areas usually appear black. Although differential printing emphasis can enhance the results there is a fundamental limitation to the penetration of such areas with infrared photography. In studying underdrawings with infrared photography it should first of all be remembered that mostly only part of the drawing is being revealed. Conclusions based on such evidence alone should be treated with circumspection.

Van Schoute[23] has pointed out that in some cases infrared photography can show various stages in the creative process in a single document precisely because it shows underdrawing and overlying paint layers at the same time. Faries[24] also published a good example of such evidence.

3. Infrared 'false colour' photography

In this technique a daylight colour film is sensitized to green, red and near infrared rather than to blue, green and red. The infrared component produces modified colour renditions[25]. Using commercially available Kodak Aero 8443 film Olin and Carter[26] were the first to publish applications of 'false colour' infrared photography to works of art. More recently Matteini *et al.* used Kodak Ektachrome IR colour film to identify pigments in Italian paintings and for distinguishing retouchings[27]. Applications have indeed been limited to conservation as may be expected since 'false colour' (infrared) photography aims generally at distinguishing areas for the human eye which are more difficult to separate in grey tones. There is little point in studying underdrawings in this way because there the aim is to obtain a document ressembling as much as possible a black drawing on a white ground.

Loose[28] has obtained results comparable to 'false colour' infrared photography but with rather better resolution by additive printing on integral tripack paper of a number of separation negatives and an infrared negative with various maskings. His results seem also to be most useful in bringing out differences in paint-layer condition.

4. Infrared image converters

Infrared image converters are photo-emissive image-forming systems with an S-1 cathode response. The responsivity is peaked at 8000 Å and has a wavelength limit of about 1.2 microns. The infrared image converter requires a light source to illuminate the object. This is the device that in German is called *Bildwandler*.

Heiber[29] seems to have been the only author who published actual results of examining paintings in this way.

Image converters could be expected to improve the detectability of underdrawings somewhat compared with infrared photography.

They allow quick inspection of a painting but registration of the converted infrared image is not very easy.

Infrared image converters have never been used systematically in the scientific examination of paintings. They are hardly being produced anymore because military developments in the last decades have been directed towards passive infrared detection devices.

5. Infrared reflectography

5.1. *Development of infrared reflectography*

Infrared reflectography was developed by van Asperen de Boer[30] in the late 1960's as a method permitting to detect underdrawings beneath green and blue areas which is usually impossible with infrared photography[31].

The first stage in the creation of a painting can thus be revealed much more completely and there is generally a great improvement in detectability over infrared photographs.

The resulting documents are obtained by imaging only a small area of the painting at a time and 'translating' the employed infrared radiation into visible radiation. The images obtained are not as sharp as good infrared photographs and have therefore been named 'infrared reflectograms' to prevent confusion and to indicate that they are not true photographs.

The first reflectograms published in 1966[32] were obtained with a modified Barnes Infrared Camera — an instrument designed as a research thermograph[33]. This sequential read-in and sequential read-out image device was equipped with a lead-sulfide detector with a peak response at about 2 microns and mirror optics. Radiation reflected from the painting is deflected from a cam-driven flat scanning mirror into the radiometer system and focused onto the detector. The detector produces a signal which is proportional to the radiation input. The amplified signal is applied to a neon glow modulator in the photographic display system. A mirror attached to the back of the scanning mirror produces a moving spot on the photographic plate and a picture is thus synchronously obtained.

The increased resolution of the instrument — 240.000 image points per reflectogram — implied extended scanning times making the production of reflectograms a rather slow process. Each reflectogram took about half an hour and the instrument was rather heavy and cumbersome to handle. Areas smaller than c. 10 cm in width on the painting could not be imaged.

Nevertheless some interesting results were obtained.

The equipment was used in 1966 in a first examination of the Van Eyck Ghent altarpiece[34] and in the following years to reflectograph a number of

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Fig. 1. Infrared reflectographic examination of the Van der Weyden Beaune Polyptych *(Photo J.R.J. van Asperen de Boer). Adjusting the position of the television camera equipped with an infrared vidicon. A small film-lamp driven at a low voltage provides the infrared radiation. The tripod allows precision scanning of larger areas. The technical staff is engaged in photographing reflectograms from the monitor screen.*

earlier Netherlandish paintings in the Rijksmuseum, Amsterdam and the Royal Museum of Fine Arts, Brussels. Some of these results have been published[35].

To obtain an explanation both for the limited results of infrared photography and for the increased detectability of infrared reflectography van Asperen de Boer applied the phenomenological theory of Kubelka-Munk to the scattering and absorption of pigments in various media in the infrared region of the spectrum concerned. Measurements on mainly oleaginous paint-layers made with pigments also used in the 15th and 16th centuries showed that such earlier paints are most transparent in the spectral region around 2 microns. For pigments such as malachite (green) and azurite (blue) a paint layer three times as thick would have to have been used to hide an underdrawing — invisible to the human eye — also from the infrared reflectograph[36].

Recently Kosolapov[37] has criticised van Asperen de Boer's explanation of observed data using elementary scattering theory. He has pointed out that the signal-to-noise ratio of infrared films is much higher than that of the infrared reflectography systems. Infrared film should thus be used for the detection of underdrawing beneath e.g. ochres. For high refracting pigments such as lead white maximum transparency is theoretically achieved around 5.5 microns according to Kosolapov who, however, was unable to reveal underdrawing in this region using an AGA 680 Thermovision system.

Van Asperen de Boer[38] indeed showed that with increasing wavelength the emission of the painting at room temperature becomes dominant over the permissible reflected radiation thus preventing the use of longer wavelength radiation. In addition his measurements showed that the contrast between the black underdrawing and the white ground decreases with wavelength. This causes the hiding thickness to decrease as well.

5.2. *Infrared vidicon television systems as reflectographs*

In view of the optimum transparency of most earlier paints around 2 microns van Asperen de Boer attempted subsequently to use more convenient infrared-to-visible image translation systems for reflectography of paintings, responsive in this wavelength region. Morton and Forgue[39], developed an infrared television pick-up tube with a long wavelength response limit of 2.1 microns capable of producing a 400-line resolution picture. This vidicon was not commercially available. Heimann and Kunze[40] later produced an infrared vidicon with a wavelength response to about 1.9 microns and a resolution of about 450 lines. This tube — with a lead sulfide target — was commercially available and was introduced in 1969 as part of an infrared vidicon television system for reflectography[41]. Since then infrared vidicons have been manufactured with a higher sensitivity and a more extended wavelength response.

Hori *et al.* published a vidicon with a wavelength response up to 2.0 microns. A similar infrared vidicon has been made commercially available by Hamamatsu[42].

As closed circuit television technology has improved in the last decade the results obtained with the later systems are rather superior to the earlier reflectograms obtained in this way.

5.3. *Operation of infrared vidicon television systems for reflectography*

The infrared vidicon television system has a number of obvious advantages over the Barnes Infrared Camera. The reflectogram can be viewed immediately on the monitor screen. The equipment is compact and can be used on a versatile tripod[43]. Higher areas of for instance large altarpieces can thus be examined without touching the painting itself.

The illuminating lamp with a quartz tube driven at low voltages through a variable resistor moves along with the television camera[44].

Infrared reflectography can be used for rapid inspection of paintings when recording is not required but usually a more permanent document is needed particularly when art historical evaluation is ensuing. The painting is then systematically scanned in vertical bands. A horizontal sledge enables the camera to be moved on the tripod in two directions. Notes are made of interesting details to be recorded later. In earlier work[45] a video-recorder was used for storing this data. The bandwidth requirement is c. 9 MHz and recorders with smaller bandwith lead to considerable loss in resolution. It is therefore preferred to record the image on the monitor screen with a photographic camera. A slow film in a 35 mm camera with macrolens at shutter speeds of ½ s or more is used. Polaroid material can be used for instant results but is more expensive.

In moving the television, camera overlappings of about one third in the horizontal and vertical directions are required[46]. The films are developed and contact prints used for documentation purposes. Assemblies of reflectograms are needed for detailed rendering of underdrawings. Using the overlappings they can be put together by pasting individual reflectograms with tape in position, cutting along verticals and horizontals and glueing onto thin cardboard. Due to the inhomogeneity of the infrared vidicon target surface considerable dodging is usually required in printing the negatives. Otherwise disturbing differences in tone occur where reflectograms touch.

5.4. *Limitations of infrared reflectography*

In order that an underdrawing can be detected by infrared reflectography it should first of all be made with a carbon-containing paint or drawing tool on a white ground.

Occasionally underdrawings seem to have been made with red chalk and are then invisible in reflectograms because the red chalk is transparent to the infrared radiation.

With the introduction of dark grounds and imprimaturas in 16th century Italian painting the detection of underdrawings becomes problematical. It is likely that in 17th century Dutch painting a sketch was often made in white chalk on a dark ground. Such a white underdrawing on a grey background can be seen in Vermeer's picture in the Vienna Kunsthistorisches Museum[47]. Another limitation is that the overlying paint layers shoud not be too thick. Sometimes thickish touches of lead-tin yellow are difficult to penetrate. Paint layers should not contain too much carbon either. Some trees in the Van Eyck Ghent altarpiece have a dark underpainting and this cannot be penetrated. The underpainted forms are revealed instead[48].

Green robes are often underpainted in black as well. The one in the Lucas van Leyden's *Last Judgement*, that of S. Peter, could not be penetrated with infrared reflectography — the only area in the triptych (cf. note 66 below).

From the middle of the 16th century on, shadows in northern European painting are more often made through admixture of black pigment rather than by glazing in the basic colour. Paintings in the group Pieter Aertsen, for instance, show many of such black shadows without relief and cannot be penetrated by infrared reflectography.

Generally one should be careful in reading reflectograms because the document often images a superposition of underdrawing and overlying paint layers. Notably eyes and eyebrows show up as they are painted frequently with the use of black pigment. Comparison with the painting itself or detail photographs is imperative. In outstanding cases there is hardly any interference of paint layers at all and one is tempted to see reflectograms as drawings in their own right.

5.5. *Future developments*

Improvements in infrared reflectography may be expected from developments in applications of image enhancement techniques. First attempts have been published or announced[49]. It is essential that the output of the infrared vidicon television system is in some way digitized. Instead of using a photographic camera reflectograms would be recorded on floppy disks or laser disks. Considerable improvement in signal-to-noise ratio may be expected while the inhomogeneity of the target surface could be compensated for. Substraction of the surface paint image might be another improvement. Some applications to facilitate assembling of images by computer have been announced[50]. Emphasis in infrared technology is on passive devices recording emitted radiation of longer wavelength than the 2 micron region used in reflectography. High optical resolution is usually not required in such systems and it is not very likely that sharper reflectograms could be obtained by using such — often military — instruments with a band-pass filter around 2 micron. Higher resolution than the actual 450-500 television lines with the best infrared vidicons could perhaps be obtained but emphasis of the manufacturers has been on increased sensitivity in view of heat detecting applications. The free parameter of the illuminating lamp in reflectography makes this unnecessary and perhaps some trade-off would be possible[51].

As has been shown previously[52] there is no point in extending the wavelength of infrared radiation used beyond the 2 micron region in infrared reflectography. The use of band-pass or spike filters for narrow wavelength bands does not improve the detection of underdrawings. Identification of pigments in this way would be theoretically possible with known reflectance spectra in the near infrared but would be complicated by the usual multi-layered paint structure.

5.6. *Applications of infrared reflectography*

5.6.1. *Conservation*

Infrared reflectography is increasingly used in conservation workshops and restoration studios as a rapid means of inspection not involving the cumbersome precautions of infrared photography. It is a useful complement to X-radiography and ultraviolet fluorescence in detecting various discontinuities in the paint surface such as damages and retouchings and is superior to infrared photography in dark areas.

Occasionally use is made of remaining underdrawing to reconstruct contours or forms where heavy paint losses are present in the painting. Very dark blackish and blue robes often become more readable and this may assist the restorer in cleaning operations. The infrared vidicon television system has also been used to examine canvas paintings in transmitted infrared radiation[53]. Drawings have been examined with this system both in reflected and transmitted light[54].

5.6.2. *Art history*

Meaningful applications in art history often require the study of a great number of paintings associated with a particular painter. This can either be achieved by traveling to the various locations with the examination equipment or by gradually acquiring data in the museums concerned. Both approaches have been initiated[55]. An exhaustive survey of the use of reflectography within art history is outside the scope of this contribution but some fields of application are mentioned below.

Flemish Primitive painting

The development of infrared reflectography was very much stimulated by the problem of the Van Eyck Ghent altarpiece and the impossibility of revealing an underdrawing beneath the green areas in the polyptych with classical infrared photography. It was therefore a prime desire to apply the method to the *Mystic Lamb*. The results of this examination were published in 1980[56].

A project to investigate the underdrawing in paintings of the group Van der Weyden/Master of Flémalle has been carried out since 1980[57]. Earlier van Asperen de Boer published reflectograms of some Van der Weyden group paintings in Belgium and Holland[58]. By the end of 1982 about forty paintings making up the core of the groups had been examined by infrared reflectography. Preliminary results have been announced and summaries published[59]. Grosshans[60] studied the Miraflores triptych.

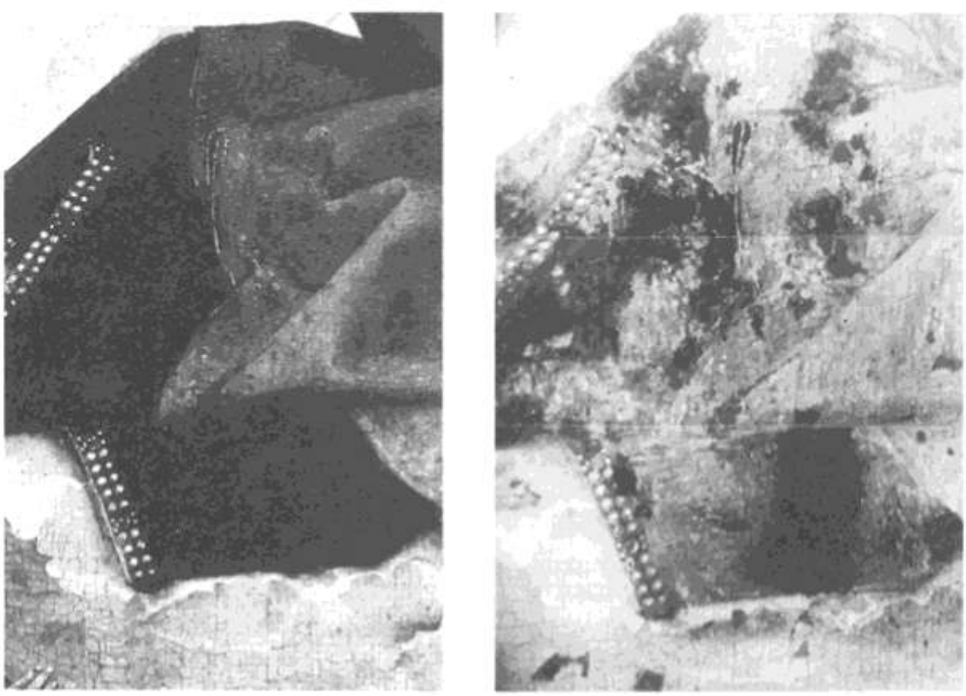

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Fig. 2. Van der Weyden Beaune Polyptych *: part of the robe of the Virgin in the third 'panel' from the left in Fig. 1 (Photo J.R.J. van Asperen de Boer).*
This painting was transferred to canvas in the nineteenth century, and the ensuing damage has been retouched. The infrared reflectogram assembly of fig. 2b shows these regions clearly also in the blue areas. Although no underdrawing can be made visible in this case because it was probably largely removed during the transfer an assessment of the state of conservation — complementary to e.g. X-radiography — is readily achieved.

Reflectography has also been used in studying paintings by Dirk Bouts and Hieronymus Bosch[61].

Later Flemish painting — notably Gerard David, Memling and Colyn de Coter — has been the subject of some investigations with infrared reflectography[62].

Dutch 16th century painting

By the end of the fifteenth century paint layers become thinner in northern European painting. In the early sixteenth century the underdrawing can often be observed partly with the naked eye. It is not surprising therefore that a number of investigations on northern Netherlandish 16th century painting have been published.

Van Asperen de Boer and Wheelock[63] studied three authenticated altarpieces by Cornelis Engebrechtsz with infrared reflectography and showed the close relationship between these underdrawings and those revealed in some panels generally attributed to the Master.

Faries[64] and van Asperen de Boer and Faries[65] have examined a great number of paintings in the group Jan van Scorel with infrared reflectography. Faries was able to distinguish between the draughtsman hands of Scorel and his assistants in some altarpieces around 1540 and these conclusions could be supported by the study of paint layer structure and composition. Filedt Kok[66] studied the entire œuvre of Lucas van Leyden with infrared reflectography and infrared photography. He has considered the relation between the underdrawing and independent drawings in this group and was able to incorporate other technical data. The beautiful washed underdrawings in the Leyden *Last Judgement* triptych almost totally free from interference of overlying paint layers in the reflectograms must be considered a valuable addition to Lucas' extant œuvre.

Grosshans[67] examined an important altarpiece by Jacob van Utrecht with infrared reflectography.

Reflectograms of paintings by Geertgen tot Sint Jans and the Master of the Brunswick diptych have been published as isolated examples. A more systematic study of underdrawings in paintings by Pieter Aertsen awaits publication.

Infrared reflectography has also been used to study underdrawings in Hispano-Flemish paintings[68].

Underdrawings have been shown to be present in Venetian paintings of around 1500, notably in panels from the group Giovanni Bellini. This feature may be used to understand somewhat better the problem of producing paintings in this period, especially for the distinction between originals and various secondary or derived versions[69]. Fifteenth century Sienese paintings also appear to have characteristic underdrawings[70].

Fig. 3a. Group Jan van Scorel, Virgin and Child. *Utrecht, Centraal Museum. Infrared photograph (Photo Central Research Laboratory for Objects of Art and Science, Amsterdam). The underdrawing is made visible in the red part of the Virgin's dress and the whitish areas but not in the blue robe.*

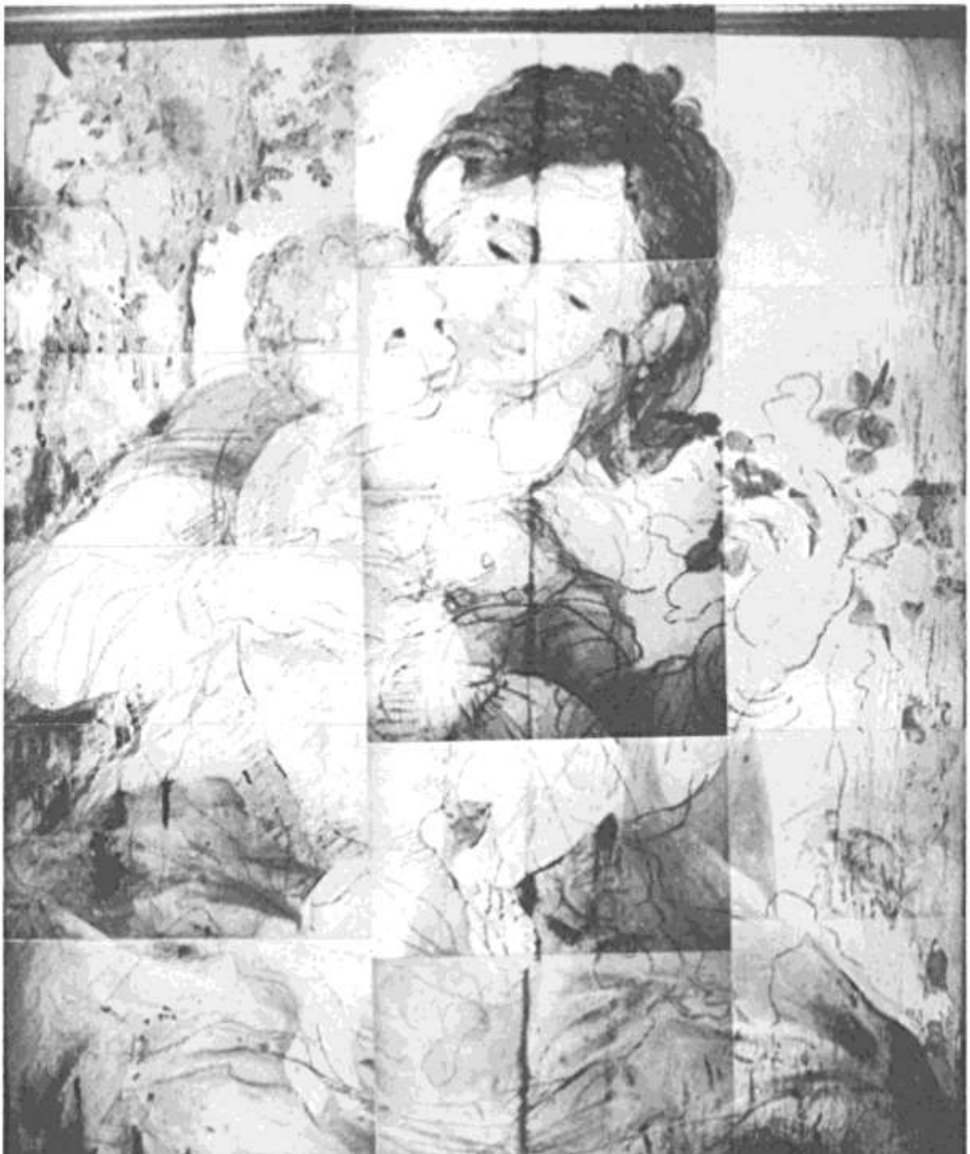


Fig. 3b. Group Jan van Scorel, Virgin and Child. *Utrecht, Centraal Museum. Assembly of reflectograms produced with the infrared vidicon television system (Grundig FA 70 television camera with Hamamatsu N 214 infrared vidicon, Kodak Wratten 87A filter and Grundig BG 12 monitor, 875 lines) (Photo J.R.J. van Asperen de Boer). The underdrawing is now also visible in the blue area showing a differently underdrawn position of the Child's legs. The dark spots in the blue robe are retouchings — probably containing some black pigment.*

Earlier German painting seems to be a most promising field for investigations with infrared reflectography. Chatelet studied underdrawings revealed in this way in paintings from the group Schongauer in Colmar[71]. Bosshard[72] published most interesting findings in paintings by Niklaus Manuel Deutsch — notably monograms in the underdrawing.

Nicolaus[73] and Bosshard[74] drew attention to the possibility of distinguishing in reflectograms the various drawing tools and materials used in underdrawing.

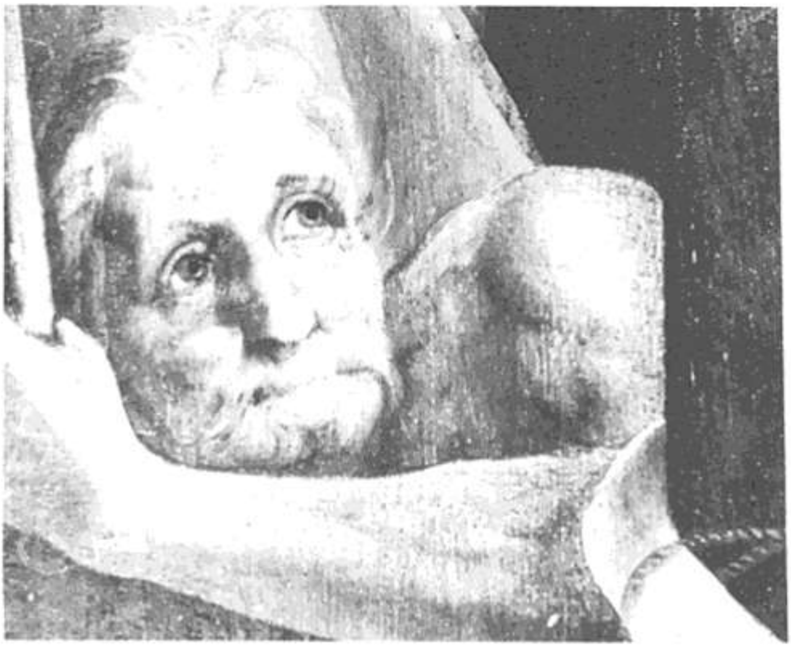
In seventeenth century painting black underdrawings on a white ground are less frequent. They do occur, however, in paintings by Saenredam[75], Jan van Goyen, Esaias van de Velde and a few others[76].

Further useful applications may arise in 19th century painting where underdrawing in black pencil appears and even in modern painting[77].

It should be remembered that examination with infrared radiation is only one method of surface examination of works of art and that optimal results will inevitably only be achieved in combination with other data and by close comparison with the original painting.

6. Notes

1. L. Larmore, *Infrared Photography*, in *Proc.Inst.Radio Engrs.*, 47, 1959, 1487-1488 ; W. Clark, *Photography by Infrared*, New York, 1946.
2. *Kodak Infrared Films*, Kodak Publications No. N-17, Rochester, 1971, p. 8. See also *Applied Infrared Photography*, Kodak Publication No. M-28, Rochester, 1982.
3. The spectral sensitivity curves of these films have been published in *Kodak Plates and Films for Science and Industry*, Kodak Publication No. P-9, Rochester, 1967, p. 25d.
   See also F. Mairinger, *Untersuchungen von Kunstwerken mit sichtbaren und unsichtbaren Strahlen*, Akademie der bildenden Künste, Vienna, 1977, p. 35.
4. *Applied Infrared Photography*, Kodak Publication No. M-28, p. 36 ff.
5. L. Loose, *Nouveau procédé de tirage infra-rouge par masquage*, in *Bulletin de l'Institut royal du patrimoine artistique*, 1, 1958, p. 85-93.
6. H.L. Nickel, *Infrarot-Kontrastaufnahmen von Gemälden*, in *Wiss.Z.Univ.Halle Ges.-Sprachw.*, IX, 1960, p. 421-424.
7. L.M. Teixeira, *Printing Infrared Negatives on Translucent Paper*, in *Studies in Conservation*, 18, 1973, p. 180.
8. G. Van de Voorde and J. Flamme, *A Simple Compensation Method in the Printing of High-contrast Negatives*, in *Bulletin de l'Institut royal du Patromine artistique*, 16, 1976/77, p. 38-55.
9. Cf. for instance W. Clark, *op. cit.* (note 1).
10. J. Desneux, *Underdrawings and Pentimenti in the Pictures of Jan van Eyck*, in *Art Bulletin*, 40, 1958, p. 13-21.
11. J. Taubert, *Zur kunstwissenschaftlichen Auswertung von naturwissenschaftlichen Gemäldeuntersuchungen*, Inaugural-Dissertation, Philipps-Universität, Marburg, 1956, chapter 8, p. 96-120. This chapter was subsequently published with illustrations in *Nederlands Kunsthistorisch Jaarboek*, 26, 1975, p. 41-72, Bussum, 1976 (*Scientific Examination of Early Netherlandish Painting*).



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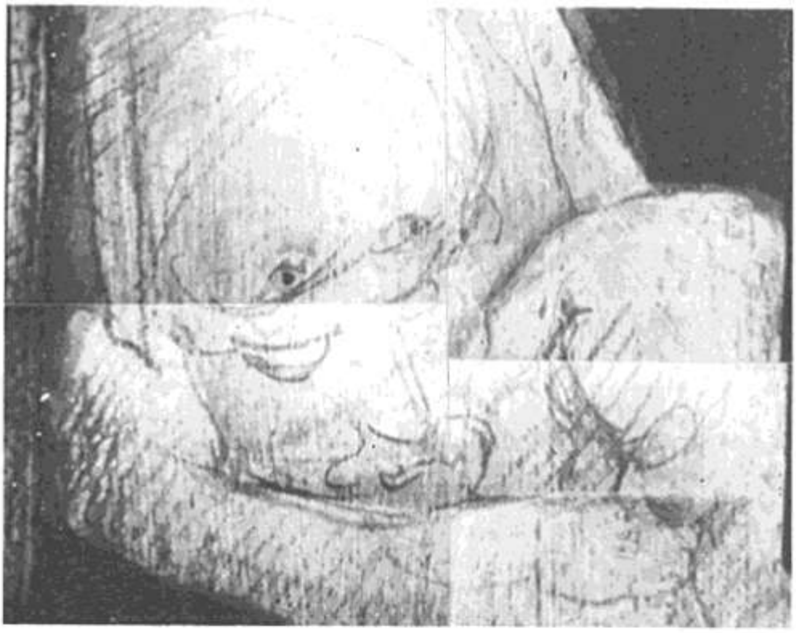

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Fig. 4. Detail of the right-hand outer wing of the 'Crucifixion triptych' *(Group Jan van Scorel) in the Rijksmuseum 'Het Catherijneconvent', Utrecht, Inv. 331.*

a. Panchromatic photograph (Photo W.J. Engelsman)

b. Assembly of infrared reflectograms (Photo J.R.J. van Asperen de Boer). The head was underdrawn in a different position. Of the overlying paint-layers mainly the eyes — containing black paint — show in the reflectograms.

12. J. Taubert, *La Trinité du Musée de Louvain. Une nouvelle méthode de critique des copies*, in *Bulletin de l'Institut royal du Patrimoine artistique*, 2, 1959, p. 20-33.
13. J. Lavalleye, *Le Palais ducal d'Urbin (Les Primitifs flamands. I. Corpus de la peinture des anciens Pays-Bas méridionaux au quinzième siècle*, 7), Brussels, 1964.
14. R. Van Schoute, *La Chapelle royale de Grenade (Les Primitifs flamands. I. Corpus de la peinture des anciens Pays-Bas méridionaux au quinzième siècle*, 6), Brussels, 1963.
15. Id., *Le dessin de peintre chez Thierry Bouts*, in *Mélanges d'archéologie et d'histoire de l'art offerts au Professeur Jacques Lavalleye*, Louvain, 1970, p. 327-333.
16. Id., *Le dessin de peintre chez Hugo van der Goes*, in *Revue des archéologues et historiens de l'art de Louvain*, 5, 1972, p. 59-66.
17. Id., *Over de techniek van Jeroen Bosch*, in *Jheronimus Bosch. Bijdragen bij gelegenheid van de herdenkingstentoonstelling te 's-Hertogenbosch 1967*, 's-Hertogenbosch, 1967, p. 72-79.
18. R. Van Schoute and H. Marcq-Verougstraete, *Le dessin de peintre (dessin sous-jacent) chez Pieter Bruegel*, in *Nederlands Kunsthistorisch Jaarboek*, 26, 1975, p. 259-267.
19. K. Arndt, *Gerard Davids 'Anbetung der Könige' nach Hugo van der Goes*, in *Münchener Jahrbuch der bildenden Kunst*, 1961, p. 153-175.
20. H. Aulmann, *Gemäldeuntersuchungen mit Röntgen-, Ultraviolett- und Infrarotstrahlen zum Werk des Konrad Witz*, Basel, 1958 ; K. Riemann, *Ein Beitrag zur Maltechnik Lucas Cranachs des Älteren*, in *Austellung Lucas Cranach 1472-1553*, Schloßmuseum Weimar, 1972 ; W. Schade, *Lucas Cranach-Seine Werke in den Sammlungen der Deutschen Demokratischen Republik*, in *Neue Museumskunde*, 16, 1973, p. 20-30 ; M. Koller, *Der Albrechtsmeister und Conrard Leib*, in *Österreichische Zeitschrift für Kunst und Denkmalpflege*, 27, 1973, p. 41-55.
21. M. Sonkes, *Le dessin sous-jacent chez Roger van der Weyden et le problème de la personnalité du Maître de Flémalle*, in *Bulletin de l'Institut royal du Patrimoine artistique*, 13, 1971/72, p. 195-206. She has also studied a wider range of Flemish primitive underdrawing using infrared photographs : M. Sonkes, *Le dessin sous-jacent chez les Primitifs flamands*, in *Bulletin de l'Institut royal du Patrimoine artistique*, 12, 1970, p. 195-225.
22. D. Hollanders-Favart and R. Van Schoute, *Bibliographie de l'infrarouge et du dessin sous-jacent, 1975-1978*, in *Le dessin sous-jacent dans la peinture, Colloque I et II*, Louvain-la-Neuve, 1979, p. 68-143.
23. R. Van Schoute, personal communication, 1977.
24. M. Faries, *Underdrawings in the Workshop Production of Jan van Scorel. A Study with Infrared Reflectography*, in *Nederlands Kunsthistorisch Jaarboek*, 26, 1975, p. 89-228, fig. 21b.
25. *Applied Infrared Photography*, Kodak Publication No. M-28, Rochester, 1972, 4 ff.
26. C.H. Olin and T.G. Carter, *Infrared Color Photography of Painting Materials*, in *International Institute for Conservation - American Group (IIC-AG), Meeting 1969*, p. 27-28.
27. M. Matteini, A. Moles and P. Tiano, *Infrared Colour Films as an Auxiliary Tool for the Investigation of Paintings*, in *ICOM Committee for Conservation, 5th Triennial Meeting Zagreb 1978, Preprints*, paper 78/1/3, 9 p. Actual colour illustrations seem never to have been published.
28. L. Loose, *Infra-rouge en couleurs et positifs en couleurs à partir de sélections trichromes*, in *Bulletin de l'Institut royal du Patrimoine artistique*, 14, 1973/74, p. 13-33.
29. W. Heiber, *The Use of an Infra-red Image-converter for the Examination of Panel Paintings*, in *Studies in Conservation*, 13, 1968, p. 145-149.
30. J.R.J. van Asperen de Boer, *Infrared Reflectograms of Panel Paintings*, in *Studies in Conservation*, 11, 1966, p. 45-46 ; Id., *Infrared Reflectography : a Method for the Examination of Paintings*, in *Applied Optics*, 7, 1968, p. 1711-1714 ; Id, *Infrared Reflectography. A Contribution to the Examination of Earlier European Paintings*. Thesis, University of Amsterdam, Amsterdam, 1970.
31. A notable exception are areas painted with paint containing only (natural) ultramarine as the blue pigment. Cf. J. Plesters, *Ultramarine Blue, Natural and Artificial*, in *Studies in Conservation*, 11, 1966, p. 62-91, esp. 72 and fig. 2,b.

32. Cf. note 30 above.
33. Thermography is used to register images caused by emitted infrared radiation and is not discussed in this chapter. Thermography has been occasionally applied in conservation notably for the detection of voids in panel paintings (B.F. MILLER, *Thermographic Detection of Voids in Panel Paintings*, in *International Institute for Conservation, Oxford Congress, 1978, Preprints*, p. 145-147), and for studying mural paintings in historic monuments : G. URBANI, *Applicazione della « termovisione » nel campo della conservazione delle opere d'arte*, in *Problemi di Conservazione*, G. Urbani (editor), Bologna n.d., 317-327 ; G. ACCARDO and D. CAMUFFO, *Microclimate inside the Scrovegni Chapel in Padua*, in *International Institute for Conservation, Vienna Congress 1980, Preprints*, p. 15-17. In both cases an AGA Thermovision 680 was used.
34. Cf. note 2 below.
35. See note 30 above.
36. More recently it has become apparent that malachite is not frequently encountered in northern European 15th and 16th century painting — where underdrawings are most common. The green in Flemish Primitive paintings is often ground copper resinate — not malachite. Such green paints are probably more transparent than malachite-containing paints.
The increase in transparency is less pronounced for highly scattering pigments such as lead white and vermilion. Lead-tin yellow was not included in the measurements but seems to have still a fairly high scattering power around 2 microns.
37. A.I. KOSOLAPOV, *Infra-red Reflectography of Paintings. Theoretical and Experimental Research*, in *ICOM Committee for Conservation, 6th Triennial Meeting Ottawa 1982, Preprints*, Paper 81/1/3.
38. J.R.J. VAN ASPEREN DE BOER 1970, *op. cit.* (note 30 above), p. 49.
39. G.A. MORTON and S.V. FORGUE, *An Infrared Pickup Tube*, in *Proc.Inst.Radio Engrs.*, 47, 1959, p. 1607-1609.
40. W. HEIMANN and C. KUNZE, *Infrarot-Vidikon*, in *Infrared Physics*, 2, 1962, p. 175-181.
41. J.R.J. VAN ASPEREN DE BOER, *Reflectography of Paintings using an Infra-red Vidicon Television System*, in *Studies in Conservation*, 14, 1969, p. 96-118. Some silicon photodiode vidicons used in visible television systems have a response in the near infrared up to about 1 micron. Results could be obtained comparable to those in infrared photography. Systems using such tubes are not infra-red reflectographs, however.
42. H. HORI, S. TSUJI and Y. KIUCHI, *An Infra-red Sensitive Vidicon with a New Type of Target*, in *Photo-Electronic Image Devices, Advances in Electrons and Electron Physics*, vol. 28A, New York, 1969, p. 253-263. See J.R.J. VAN ASPEREN DE BOER, *A Note on the Use of an Improved Infrared Vidicon for Reflectography of Paintings*, in *Studies in Conservation*, 19, 1974, p. 97-99. The Hamamatsu infrared vidicon first used by him for reflectography was responsive up to c. 2.4 microns. More recent vidicons produced by Hamamatsu are responsive up to 1.85 microns (N 214) and c. 2.2 microns (N 214-06).
43. The illustrations in this chapter are of reflectograms made with the author's equipment consisting of a Grundig FA 70 television camera mounted on a sturdy professional Linhof tripod ; extension pieces can be mounted on this tripod and a 90 cm sledge is used. The monitor is a Grundig BG 12. The system has 875 television lines. A Kodak Wratten 87A filter is placed behing the lens in front of the Hamamatsu N 214 vidicon. The automatic controls of gain, plate voltage and diaphragm should be disconnected. The plate voltage should be made manually controllable.
44. The sensitivity of the system is high enough to obtain reasonable reflectograms with no other illumination than the spotlights used in some museums for permanent lighting. There is thus no danger of heating the painting unduly (cf. also VAN ASPEREN DE BOER, 1970 — note 30 above —, p. 52, 53).
45. J.R.J. VAN ASPEREN DE BOER and A.K. WHEELOCK JR., *Underdrawings in some Paintings by Cornelis Engebrechtsz*, in *Oud Holland*, 87, 1973, p. 61-94.
46. Gerald Schultz of Berlin has introduced a grid of very thin wires over the painting. This facilitates subsequent assembling of reflectograms but would seem only feasable in studio conditions.

47. Cf. also H.J. KUHN, *A Study of the Pigments and Grounds used by Jan Vermeer*, in *National Gallery of Art. Report and Studies in the History of Art*, Washington D.C. 1968. Kühn's investigations showed that a large number of Vermeer paintings have a grey ground, which supports the credibility of the painter depicting his own working method.

48. J.R.J. VAN ASPEREN DE BOER, *A Scientific Re-examination of the Ghent Altarpieces*, in *Oud Holland*, 93, 1979, p. 141-214, esp. note 52 and figs. 50-54.

49. S. MIURA and R. ISHIKAWA, *Recent Applications of an Infrared TV Camera*, in *Hozon Kagaku (Science for Conservation)*, 19, 1980, p. 21-28 ; J.R. DRUZIK, D. GLACKIN, D. LYNN and R. QUIRUS, *Applications of Computer based Image Processing useful in Conservation*, in *Preprints AIC Meeting*, 1982, Milwaukee, p. 71, 72 ; see also J.R.J. VAN ASPEREN DE BOER, *The Study of Underdrawing. An Assessment*, in *Le dessin sous-jacent dans la peinture, Colloque V. 1983*, Louvain-la-Neuve, 1985, p. 12-22.

50. M. AINSWORTH, personal communication, August 1982. A poster session entitled *Application of Digital Image Processing to Problem in Art* by her and co-workers was announced at the International Institute for Conservation, 1982, Washington Congress.

51. National Materials Advisory Board, *Materials for Radiation Protection*, Publ. NMAB 287, National Academy of Sciences, Washington D.C., Jan. 1974, p. 172-175, 302-303. Methods of improving the uniformity and sensitivity of intrinsic photoconductors suitable for application in infrared vidicons is recommended. It would seem, however, that little progress has been achieved since.

52. J.R.J. VAN ASPEREN DE BOER 1970, *op. cit.* (note 30 above), p. 49.

53. J. MILLS, personal communication, 1974. Cf. also H. LANK, *Titian's 'Perseus and Andromeda' : Restoration and Technique*, in *The Burlington Magazine*, 124, 1982, p. 400-406, esp. note 5.
Dan. A. KUSHEL, *Applications of Transmitted Infrared Radiation to the Examination of Artifacts*, in *Studies in Conservation*, 30, 1985, p. 1-10, has called the resulting documents 'infrared transmittograms'.

54. Gillian Lewis, National Maritime Museum, Greenwich (personal communication) uses reflectography often for the study of drawings on paper. This is borne out Shelley FLETCHER, *A Preliminary Study on the Use of Infrared Reflectography in the Examination of Works of Art on Paper*, in *ICOM Committee for Conservation, Preprints 7th Triennial Meeting*, Copenhagen, 1984, 84.14.24-28.

55. Notably by FARIES and VAN ASPEREN DE BOER in their research on Jan van Scorel (note 24 above) and in the project on underdrawing in the Van der Weyden/Flémalle group. FARIES has recently made a systematic survey in the National Gallery in Washington D.C. (M. FARIES, *The Survey of 15th and 16th Century Northern European Panel Painting in the National Gallery with Infrared Reflectography*, unpublished typescript, 1982). K. GRIMM and the author carried out in 1982 a similar preliminary survey in the Fürstliche Sammlungen in Donaueschingen.
See also VAN ASPEREN DE BOER, Louvain-la-Neuve, 1985, *op. cit.*, note 49 above.

56. J.R.J. VAN ASPEREN DE BOER, *op. cit.* (note 48 above).

57. J.R.J. VAN ASPEREN DE BOER, *A Project to investigate Underdrawings in the Group Van der Weyden/Flémalle*, in *Le dessin sous-jacent dans la peinture. Colloque III*, Louvain-la-Neuve, 1979, p. 105-107.

58. J.R.J. VAN ASPEREN DE BOER, *op. cit.* (note 30 above), plate VIII-XX.

59. J.R.J. VAN ASPEREN DE BOER, W.J. ENGELSMAN, J.P. FILEDT KOK and R. VAN SCHOUTE, *A Progress Report on the Investigation of the Underdrawing in the Paintings of the Group Van der Weyden/Flémalle*, in *Le dessin sous-jacent dans la peinture. Colloque IV*, Louvain-la-Neuve, 1981, p. 98-102 ; J.R.J. VAN ASPEREN DE BOER, C.M.A. DALDERUP, J. DIJKSTRA, J.P. FILEDT KOK and R. VAN SCHOUTE, *A Progress Report (II) on the Investigation of Underdrawing in the Paintings of the Group Van der Weyden/Flémalle*, in *Le dessin sous-jacent dans la peinture. Colloque V*, Louvain-la-Neuve, 1985, p. 208-210.

60. R. GROSSHANS, *Rogier van der Weyden. Der Marienaltar aus der Kartause Miraflores*, in *Jahrbuch der Berliner Museen*, 23, 1981, p. 48-112.

61. R. Van Schoute and J.R.J. van Asperen de Boer, *Het 'Laatste Avondmaal' van Dirk Bouts. Een onderzoek met infraroodreflectografie*, in *Tentoonstellingscatalogus 'Dirk Bouts en zijn tijd'*, Leuven, 1975, p. 388-393.
J.P. Filedt Kok, *Underdrawing and Drawing in the Work of Hieronymus Bosch : a Provisional Survey in Connection with the Paintings by him in Rotterdam*, in *Simiolus*, 6, 1972/73, p. 133-162.
62. C. Périer-d'Ieteren, *L'apport de la réflectographie dans l'infra-rouge à l'examen de quelques peintures flamandes des XV^e^ et XVI^e^ siècles*, in *ICOM Committee for Conservation 5th Triennial Meeting Zagreb, 1978*, paper 78/1/4.
Id., *Précisions sur la technique d'exécution des peintures de Gerard David*, in *ICOM Committee for Conservation. Preprints 7th Triennial Meeting*, Copenhagen, 1984, 84.1.38-43.
Id., *Colyn de Coter et la technique picturale des peintres flamands du XV^e^ siècle*, Brussels, 1985.
M. Ainsworth, *The Technique of Underdrawings. Some Preliminary Observations of Works in the Metropolitan Museum of Art*, in *Le dessin sous-jacent dans la peinture. Colloque V*, Louvain-la-Neuve, 1985, p. 53-60.
M.C. Garrido and D. Hollanders-Favart, *Le dessin sous-jacent dans l'œuvre de Memling. Le triptyque de l'Adoration des mages au Musée du Prado et le triptyque dit de Jan Floreins au Memling Museum de Bruges, ibid.*, p. 198-204.
63. See note 45 above.
64. M. Faries, *op. cit.* (note 24 above).
65. J.R.J. van Asperen de Boer and M. Faries, *Research during the Jan van Scorel in Utrecht Exhibition : A Report*, in *Simiolus*, 9, 1977, p. 169-182.
66. J.P. Filedt Kok, *Underdrawing and other Technical Aspects in the Paintings of Lucas Van Leyden*, in *Nederlands Kunsthistorisch Jaarboek*, 29, 1978, p. 1-184.
67. R. Grosshans, *Bilder im Blickpunkt. Jacob van Utrecht. Der Altar von 1513*, Berlin-Dahlem, 1982.
68. J.M. Cabrera and M.C. Garrido, *Dibujos subyacentes en las obras de Fernando Gallego*, in *Boletín del Museo del Prado*, 2, No. 4, 1981, p. 27-48.
69. H.W. van Os, J.R.J. van Asperen de Boer, C.E. de Jong-Janssen and C. Wiethoff, *The Early Venetian Paintings in Holland*, Maarssen, 1978.
70. This is notably the case for paintings in the group Giovanni di Paolo. Preliminary results obtained by the author in 1982 will be pursued. Underdrawings of various form and function have been detected in paintings from the Group Raphael. See *The Princeton Raphael Symposium*, 1983, Princeton University Press (in press).
71. A. Chatelet, *Schongauer : premières observations*, in *Le dessin sous-jacent dans la peinture. Colloque IV*, Louvain-la-Neuve, 1982, p. 144-151.
72. E.D. Bosshard, *Fortschritt in der naturwissenschaftlichen Gemäldeuntersuchung. Die Erforschung der Unterzeichnung mit dem Infrarot-Fernsehgerät*, in *Zeitschrift für Schweizerische Archäologie und Kunstgeschichte*, 39, 1982, p. 76-80.
73. K. Nicolaus, *Gemälde im Licht der Naturwissenschaft. Austellungskatalog*, Braunschweig, 1978.
74. E.D. Bosshard, *op. cit.* (note 72 above).
75. J.R.J. van Asperen de Boer, *De ondertekening bij Pieter Saenredam*, in *Bulletin van het Rijksmuseum*, 19, 1971, p. 21, 25-31 ; R. Ruurs, *Saenredam : Constructies*, in *Oud Holland*, 96, 1982, p. 97-121, esp. 97.
76. K. Nicolaus, *op. cit.* (note 73), fig. 58 and H. Bjerre, *Forsiden. Museumsmagasinet 1, Meddelelser fra Danmarks Museer*, October 1977 for reflectograms of paintings by Esaias van de Velde. The author with Bernice Tjemkes has encountered quite a number of underdrawings in a fairly systematic survey of Jan van Goyen and Esaias van de Velde paintings in Dutch museums (1981-82).
77. A construction in pencil with two colour notations was revealed in August 1982 beneath Theo van Doesburg's 'Heroic Movement'. Catalogue Exhibition Stedelijke Museum. See H. De Herder, *Theo van Doesburg-« Heroische Beweging ». Verslag van een restauratie*, in *Mededelingenblad IIC Nederland*, 2, september 1984, p. 3-7.
Underdrawing in Picasso's *Guernica* was revealed by infrared reflectography in a a recent examination : J.M. Cabrera and M.C. Garrido, *Estudio técnico del Guernica*, in *Boletin del Museo del Prado*, II, 6, 1981, p. 147-156.

7. Résumé

Les principes de la photographie à l'infrarouge sont décrits ; quelques aspects pratiques (filtres, sources de radiation, tirage, etc...) sont mentionnés. Des applications à l'histoire de l'art — le plus souvent pour mieux voir un dessin sous-jacent — sont citées. Les limitations de la photographie à l'infrarouge sont indiquées.

La photographie en couleurs fausses à l'infrarouge et les convertisseurs d'image dans l'infrarouge n'ont pas eu beaucoup d'applications dans l'examen des œuvres d'art. La réflectographie à l'infrarouge développée par l'auteur dans les années 1960 est de plus en plus employée pour l'examen des peintures. Les principes théoriques, les divers équipements et les limitations de ce procédé sont énumérés. Un dessin sous-jacent quand il est présent sur la préparation blanche d'un tableau est généralement aussi détecté sous des couches picturales bleues et vertes, impénétrables par la photographie à l'infrarouge.

Des applications dans le domaine de la conservation et surtout de l'histoire de la peinture des XV^e^ et XVI^e^ siècles sont mentionnées. Quelques réflexions sur des développements possibles sont incluses.