Identification and Suppression of Thermal Reflections in Infrared Thermal Imaging

M. Vollmer, S. Henke, D. Karstädt, K.-P. Möllmann, and F. Pinno
University of Applied Sciences, Brandenburg

ABSTRACT

Thermal reflections are a common source of problems in interpreting infrared (IR) thermal images. In particular, atomically smooth surfaces like glass, metals, or wet surfaces, and also brick and concrete, may easily give rise to reflections of infrared radiation from often uncared sources. If unnoticed, these thermal reflections may give rise to misinterpretations of the object temperature. After analyzing the differences between object IR radiation and thermal reflections theoretically, possibilities to suppress or at least identify such reflections by use of IR polarizers are discussed. Theoretical predictions and experimental results are very promising.

**Keywords:** infrared, thermography, thermal reflections, Fresnel equations, IR polarizers

INTRODUCTION

In conventional optics in the visible spectral range, it is common knowledge that flat polished surfaces reflect part of the incident light, whereas the other part is refracted into the material (Figure 1). In physics and technology, reflection is used in two different ways. First and primarily, reflection means the specular reflection, i.e., the reflection, described by the law of reflection:

\[ \alpha_1 = \alpha_1' \]

where the angles are defined as in Figure 1. The more common case of slightly rough surfaces – which dominate our everyday life - leads to diffuse scattering of incident light as shown in Figure 1, bottom. For perfect diffusely scattering surfaces, the angular distribution is the one of a Lambertian source.

---

**Figure 1.** Law of specular reflection and refraction (upper left) and transition from “normal specular reflection (upper right) to diffuse scattering (lower left and right).
In the following, we refer to specular reflection when meaning conventional mirror reflection. Whenever diffuse scattering is meant, we will explicitly say so.

Depending on the amount of reflected light, reflection is used for mirrors that should have reflectivities $R$ close to 100% (1.00). Smaller reflectivities ($R<1$) occur for every boundary between two media. In detail, the reflectivity is found by using the law of reflection to find the angle and then Fresnel’s equations [1] to compute the reflectivity. The material input parameter is the index of refraction, which is real for transparent materials and complex for absorbing materials. As an example for transparent materials, Figure 2 depicts the reflectivity for light impinging from air onto glass, characterized by an index of refraction $n=1.5$. Obviously, the reflectivity strongly depends on the polarization of the incident light. The latter is given as the orientation of the electric field of the electromagnetic wave with respect to the plane of incidence, which is defined by the $k$-vector, i.e., the propagation direction of the light and the vector normal to the boundary of the surface. Usually, as in Figure 2, the plane of incidence is the drawing plane.

![Figure 2. Fresnel equations for a transparent material, defined by $n=1.5$. This can, e.g., be the transition from air to glass for visible light.](image)

In this case, normal incidence ($\alpha = 0^\circ$) leads to 4% reflection. In the inset of Figure 2, the plane of incidence is the plane of drawing. Obviously, light polarized parallel (p or $\pi$) to the plane of incidence is not reflected at all if the angle of incidence is Brewster’s angle, defined by $\tan\alpha = n_2/n_1$. Therefore, the reflected light is polarized perpendicular (s or $\sigma$) to the plane of incidence. This fact is used in photography: strong reflections from glass surfaces may easily be suppressed by use of polarizing filters (Figure 3).

![Figure 3. Example of suppression of the strongly polarized reflected visible light. Upper left: Experimental set up with the angle of incidence being close to Brewster’s angle. Upper right: View of camera without polarizing filter. Lower left and right: With filter parallel and perpendicular to the polarization of the reflected light.](image)
The reflection may be calculated not only for transparent bodies, but also for absorbing materials like, e.g., metals. Theory gives similar results, the main difference being that the materials are characterized by a complex index of refraction. The resulting reflectivity diagrams look similar to those for transparent materials (Figure 4); however, the minimum of the reflectivity usually does not reach zero; i.e., the reflected light is only partially polarized. Still, polarizing filters may be useful in partially suppressing reflections.

![Figure 4. Reflectivity from a Cu surface at \(\lambda=500\text{nm}\) according to the Fresnel equations \((n\approx 1.12+i2.6)\).](image)

The situation is very similar when moving from visible light to the thermal infrared spectral region. Depending on the materials under consideration and on the wavelength range, one may have non-absorbing transparent materials like, e.g., NaCl \((\lambda<20\mu\text{m})\) or absorbing materials like, e.g., metals.

Compared to the visible spectral range, the situation may even become worse, regarding reflections, as illustrated in Figure 5. It depicts an old brass plate, which is covered by oxide.

![Figure 5. An oxidized old brass plate with a lot of surface roughness in the 1\(\mu\text{m}\) scale or below is scattering light diffusely for visible light, but at least in part specularly for thermal IR radiation of \(\lambda\approx 10\mu\text{m}\).](image)

This plate is an atomically rough surface, as can be seen in the visible spectral range: no direct reflection can be seen. Investigating with a LW infrared camera in the wavelength range from 8-14\(\mu\text{m}\), one immediately sees reflections from the plate. Obviously, the plate is a poor mirror in the visible, but a good mirror in the infrared. This behavior is due to the relation of surface roughness versus wavelength of the radiation. If \(\lambda\) is smaller or of the order of the dimension of the surface roughness, light is scattered diffusely; i.e., no good mirror image is seen. For wavelengths much larger than the roughness dimensions, the radiation is specularly reflected as from a mirror. A classic analogy: a soccer ball will be reflected most probably according to the law of reflection from a mesh wire, if the mesh dimension is much smaller than the ball diameter. Now imagine using smaller balls…
In Figure 5, the IR wavelengths are more than a factor ten larger than the visible wavelengths, and one easily observes the transition from diffuse scattering to specular reflections [2]. This transition is also important when studying emissivities of metal surfaces [3].

Figure 6 (left) gives the specular reflectivity of the brass plate, as measured for an angle of incidence of 20° with respect to an optically polished Au surface for wavelengths from about 1.5 µm to 25 µm. Measurements were performed with FTIR spectroscopy [4,5]. Obviously, the reflectivity strongly decreases towards the visible spectral range, i.e., mostly diffuse scattering takes place in the visible, explaining why no mirror image is seen. In contrast, at wavelengths of 10µm, the reflectivity already amounts to about 70%, which leads to the mirror image of Figure 5.

In order to correlate the low specular reflectivity, i.e., the large portion of diffuse scattering, to surface roughness, a small piece of the brass plate was analyzed with conventional microscopy, dark field microscopy, and scanning electron microscopy. The right side of Figure 6 shows one typical example of an area of about 100µm x 165µm, magnified with a light microscope. There are some scratches across the surface with widths in the 1-5µm range and lengths of mm or more. In addition, there are many "point like" structures in the range of 1-3 µm as well as some larger ones, as is revealed by studying more pictures and also electron micrographs. So far, no statistical analysis of roughness was made. These structures are interpreted as surface roughness and are thought of as being responsible for the transition from specular to diffuse scattering. Their dimensions nicely correspond to the expectations according to the wavelength of visible and IR radiation.

The consequence of this discussion: flat and polished surfaces, in particular all kinds of metal surfaces, may easily result in reflections of IR radiation, even if they are not reflecting in the visible range. Therefore, all analysis of infrared thermal images must consider the possibilities of thermal reflections.

If unnoticed, thermal reflections may be misinterpreted as sources of heat on the surfaces of the investigated reflecting bodies. There are many possible thermal sources available as origin for the reflections: e.g., the sun for outdoor thermography or moving sources like humans for indoor thermography in the vicinity of objects under consideration. The present work deals with methods to identify thermal reflections and discusses possibilities for suppressing them.

In order to achieve this, we studied in detail the use of polarizers of thermal infrared radiation for short wave (3.5-5.5µm) as well as long wave (8-14µm) camera systems. The underlying principle is the same as for suppression of reflections in visible photography: we apply Fresnel’s formulas to suppress the radiation, polarized perpendicular to the plane of incidence. We discuss the specific problems of the method and
demonstrate that, for a variety of materials, this technique is sometimes very useful to strongly suppress thermal reflections. In all other cases, it offers an easy means to identify such reflections.

**EXAMPLES OF FRESNEL EQUATIONS FOR SELECTED MATERIALS IN THERMAL INFRARED**

In the following, a number of selected materials will be discussed with respect to their reflection properties in the wavelength ranges of IR camera systems. The examples were computed for one set of optical parameters, although sometimes several sets were available [6]. This is, of course, due to the fact that surface properties may be appreciably changed by oxidation or corrosion; hence, all theoretical examples should only give indications, which must be verified by experiment.

A quantitative description of how good the suppression by polarizers may be is possible by introducing the parameter \( z \), which is defined for the angle \( \phi_{\text{min}} \) of the minimum of the \( R_p \) curve

\[
z = \frac{(R_a(\phi_{\text{min}}) - R_p(\phi_{\text{min}}))}{R_a(\phi_{\text{min}})}.
\]

\( z=1 \) would offer the possibility of complete suppression, whereas \( z \) close to zero refers to the case of very small minima, i.e., nearly no chance of suppression.

In addition, practical requirements would favor small Brewster angles. These are, however, often not realized. In this case, it would be helpful to at least get partial suppression or identification of thermal reflections. Hence, the following discussion should focus on the minimum angles as well as on the parameter \( z \). In the aforementioned example of Figure 2, \( z=1 \) at 56.3°, and for copper in the visible (Figure 4), \( z=0.54 \) at around 70°.

**Metals**

The most widely used metals are either iron and iron alloys or aluminum. Figure 7 depicts the reflectivity of iron for selected wavelengths in the SW and LW camera ranges. Similarly, Figure 8 gives examples for aluminum. The plots of Figures 7 and 8 are representative for the SW and LW region of thermography, since the optical constants are slowly but monotonously increasing functions with wavelength. Obviously, the minima for \( R_p \) are at very large angles, i.e., nearly grazing incidence, for these (and many other) metals. This is not suitable for practical field work. Hence, a first conclusion is that suppression of thermal reflections will not be applicable to pure metal surfaces. However, even at angles in the range of 40° to 60°, many metals have \( z \)-values in the range of several percent. This may be sufficient to at least identify thermal reflections.

![Figure 7. Reflectivities (vertical axis) versus angle of incidence (horizontal axis) for iron. Left: \( \lambda=4.44 \mu m, n=4.59+i13.8; \phi_{\text{min}}=86^\circ, z(86^\circ)=47\%, z(60^\circ)=12.5\% 
Right: \( \lambda=10.0 \mu m, n=5.81+i30.4; \phi_{\text{min}}=88^\circ, z(86^\circ)=32\%, z(60^\circ)=3.6\% 

InfraMation 2004 Proceedings
Figure 8. Reflectivities (vertical axis) versus angle of incidence (horizontal axis) for aluminum.
Left: $\lambda=4.51\mu m$, $n=7.61+i44.3$; $\varphi_{\text{min}}=89^\circ$, $z(86^\circ)=28\%$, $z(60^\circ)=2.2\%$
Right: $\lambda=10.0\mu m$, $n=25.3+i89.8$; $\varphi_{\text{min}}=89^\circ$, $z(86^\circ)=40\%$, $z(60^\circ)=1.7\%$

**Nonmetals**

In contrast to metals, other materials of practical use that are absorbing in the IR offer much better possibilities. Figure 9 illustrates the reflectivities for glass ($\text{SiO}_2$).

In the short wave region, $z=1$, i.e., 100% suppression should be possible at Brewster’s angle. Even for angles of, say, >30°, an appreciable partial suppression should be possible. Due to the absorption maximum of glass in the range from 8-10µm with a peak around $\lambda=9\mu m$, a long wave camera would not allow perfect suppression. But again, very satisfying results are already expected for angles >30°.

As a final example, Figure 10 depicts silicon. This example is motivated by investigations to study the temperatures of silicon wafers in situ with IR imaging. However, due to the large real part of the index of refraction of Si of about 3.4, silicon wafers are very good mirrors for thermal radiation; hence, suppression of reflections is essential for correct measurements.
Figure 9. Reflectivities (vertical axis) versus angle of incidence (horizontal axis) for glass ($\text{SiO}_2$).
Upper left: $\lambda=4.55\mu m$, $n=1.365+i0.000256$; $\phi_{\text{min}}=54^\circ$, $z(54^\circ)\approx1$
Upper right: $\lambda=8\mu m$, $n=0.4113+i0.323$; $\phi_{\text{min}}=23^\circ$, $z(23^\circ)\approx50\%$
Lower left: $\lambda=10\mu m$, $n=2.694+i0.509$; $\phi_{\text{min}}=70^\circ$, $z(70^\circ)\approx1$
Lower right: $\lambda=12.05\mu m$, $n=1.615+i0.267$; $\phi_{\text{min}}=58^\circ$, $z(58^\circ)\approx1$

Figure 10. Reflectivities for silicon.
$\lambda=10\mu m$, $n=3.4215+i6.76\cdot10^{-5}$; $\phi_{\text{min}}=75^\circ$, $z(75^\circ)\approx1$
The optical constants are nearly constant across the region of SW and LW thermal IR radiation; hence, results for $\lambda=4\mu m$ look exactly the same as for the example of $10\mu m$.

An obvious preliminary conclusion of the theoretical investigation is that the use of polarizing filters should be useful in suppressing thermal reflections for many materials, with the exception of metals where the minimum angles lie close to grazing incidence. A number of practical materials behave similarly to the shown examples. For example, much furniture and wood used for indoor applications are treated with lacquers; i.e., they are varnished to give very smooth surfaces. These behave similarly to thin glass films. (It is just a different index of refraction!). Practical examples will be discussed below.

SUPPRESSION OF THERMAL REFLECTIONS: LABORATORY EXPERIMENTS

In order to verify the theoretical predictions and study the applicability for suppression of thermal reflections, a series of laboratory experiments have been carried out. The principle set up is similar to the one shown in Figure 3. The objects under study emit unpolarized IR radiation, which should be used for IR analysis. In addition, there are the disturbing thermal reflections from the warmth of hot objects in the surroundings. These reflections correspond to partially polarized radiation, which may be eliminated by appropriate polarizers.

The Polarizers

The polarizers must be of a material that is transparent for IR radiation. We decided to use polarizers with an aperture of 50mm, made of Ge for the LW range and CaF$_2$ for the SW range. (In principle, the Ge polarizer can also be used for the SW range). In this work, only results with the LW camera and the Ge polarizer are reported. The polarizing function is due to small metal strips, 0.12µm wide and made of aluminum, that are on top of the Ge substrate with a grating constant of about 0.25µm. Similar to metal grids for microwave radiation
or the Polaroid foils [1], only radiation with the electric field vector pointing perpendicular to the strips will be transmitted. The Ge polarizer is equipped with an AR coating in order to minimize reflection losses.

**Dependence of Suppression of Thermal Reflections on Angle of Incidence**

The principal setup for quantitative angularly resolved measurements of reflectivity is shown in Figure 11. It was developed to simplify the experiments in keeping the IR source for the thermal reflections, a globar with T from 1000°C to 1500°C, and the detector, i.e., an IR camera, at fixed positions, while at the same time, easily fulfilling the condition of the law of reflection. The whole assembly is mounted on a transparent plate with angular scale. With this assembly, angular measurements in the range between 27° to 85° are possible. For very large samples, the angular range can be extended to 89°, i.e., grazing incidence, which is necessary for metals.

![Figure 11. Arrangement for letting IR source and IR camera at fixed positions.](image)

Using this setup, a number of precise measurements have been carried out with, e.g., aluminium, iron, SiO2 (glass), or Si. The results confirm the theoretical expectations according to the Fresnel equations. Details of the laboratory experiments will be published elsewhere [7].

**Direct Experimental Measurement of Reflectivity Curves**

For selected materials, wave-length dependent measurements of the reflectivities for parallel and perpendicular polarization were done. For polished and smooth surfaces, no deviations from the predictions of Fresnel’s formulas are expected. If surface roughness comes into play, the influence of diffuse scattering could give rise to discrepancies. The experiments were done with the reflection accessory of the FTIR spectrometer, mentioned above. For selected angles, reflection spectra were recorded. Therefore, in principle, the spectra for all wavelengths are available. Figure 12 depicts some results for a silicon wafer, together with an extended view of the theoretical prediction, which was shown in Figure 10. The experimental
values nicely coincide with the predictions for p-polarization. However, deviations are seen for the very large angles of 87°. They are due to the limited diameter of the sample.

Figure 12. Angular dependence of the reflectivities \( R_p \) and \( R_s \) for silicon at wavelength 10\( \mu \)m and 3.33\( \mu \)m in comparison to theoretical expectations.

IDENTIFICATION AND SUPPRESSION OF THERMAL REFLECTIONS: PRACTICAL EXAMPLES

In the following, three applications will be shown. On the one hand, glass and polished and varnished wood are treated, since they are important in the everyday life of thermographers. On the other hand, thinking of potential industrial applications, the usefulness of the method for silicon wafers is demonstrated.

Glass Plate

Figure 13 depicts the IR image of a person, bending over a horizontal table with a vertically oriented glass plate. Obviously, there are some thermal reflections at the table and very pronounced ones from the glass plate.

Figure 14 shows the same scene through the IR polarizer being oriented either parallel or perpendicular to the plane of incidence. The scene is shown for the same temperature scale as Figure 13 in the upper row. In the lower row, the scale was modified to get a similar overall image. The difference of the IR camera readings are, of course, due to the fact that the filter was just placed in front of the IR camera, which itself was not calibrated with this filter. Results are, hence, more or less only qualitative.

Figure 14 nicely demonstrates the more or less complete suppression of the thermal reflections. According to Figure 9, it is not possible to easily attribute a specific Brewster angle for the \( \lambda \)-range from 8-14\( \mu \)m to glass, since the reflectivity curves vary appreciably. Therefore, the angle was optimized for these images; it was probably around 60°. For different angles, the suppression would only be partial, but still sufficient to identify disturbing thermal sources (see “Silicon Wafer” below).

Glass is present in many applications of thermography, in particular building thermography, and care should thus be taken to assure that signals indicated by the IR camera are real and not due to reflections. Similar effects are possible for polished and varnished wood.
Figure 14. Person as source for thermal reflections from a glass plate as observed through an IR polarizer oriented perpendicular or parallel to the plane of incidence.

Varnished Wood

Varnished wood has very smooth surfaces, similar to thin films. Hence, specular reflections are to be expected, in particular for large angles of incidence. Figure 15 depicts the visual image of a person leaning against a wooden wall of a lecture hall. The IR image immediately shows very pronounced thermal reflections. In Figure 16, images of the same scene were recorded while looking through the Ge polarizer. Similar to Figure 14, the T-scale was changed to better demonstrate the suppression of the reflections.

Figure 15  Thermal reflections of a person from a wooden wall.  
Left: Visual image. Right: Close-up view with LW IR camera.
Silicon Wafer

As a final example, the thermal reflections from a silicon wafer were studied. The set up was the same as with the glass experiment (Figures 13 and 14). It is shown in Figure 17 (upper row). A perfect mirror image is seen clearly in the visible as well as in the IR (lower left). In particular, the reflections from the wafer and the glass can be studied simultaneously. Rotating the polarizer (lower row) at an angle of incidence of about 75°, the thermal mirror image on the wafer is more or less suppressed completely; however, the lower right figure also demonstrates that one may still see part of the thermal reflection on the glass. According to Figure 9, the angle of 75° does not allow complete suppression. This is an example of how the method works if the angle is not perfect: there is only partial suppression, but this is sufficient to at least identify thermal reflection sources.
OUTLOOK

A simple technique to suppress and identify thermal reflections in IR imaging has been presented. The principle idea is to use IR polarizing filters. Thermal reflections follow Fresnel equations; hence, the reflected radiation shows a strong dependence of polarization versus angle of incidence. In contrast, the thermal radiation originating from objects under study is unpolarized.

The results, demonstrated for several materials, are very encouraging, and the method can probably be applied to a much wider range of materials. To our knowledge, nothing comparable is available commercially so far. We suggest introducing polarizing units as optional accessories, which should be calibrated for the given IR camera system. The cost would probably be due mostly to the price of the polarizers; therefore, it should be in the same range as that of special telephoto or close up IR lenses.

Having the option of quickly checking with a polarizer at various angles before deciding upon a temperature anomaly could result in faster work and more confidence in the results of IR imaging.

REFERENCES


ACKNOWLEDGEMENTS

We gratefully acknowledge the support of the applied research grant 17 094 02 from the German Federal Ministry of Education and Research.