On the Visibility of the Shroud Image

Author: J. Dee German

ABSTRACT

During the 1978 STURP tests on the Shroud of Turin, experimenters observed an interesting phenomenon: the contrast between the image and the non-image areas of the cloth appears to increase as the distance between the Shroud and the observer (or camera) increases. At close distances, much of the image is barely perceptible. However, at longer distances, the image in general appears darker than the surrounding native cloth and the relative shade difference between the more intense image areas; such as the nose, cheeks, pectorals and knees; and the lighter portions of the image increases. To attempt to explain this effect, a hypothesis was proposed for the cause of this counter-intuitive phenomenon (longer distance produces increasing perception of detail) based on varying diffusivity of light reflections from the cloth. In this paper, support for the hypothesis is developed analytically, demonstrated with experimental results, and compared with a computer graphics reflection model. Conclusions include a discussion of the implications of these results to other areas of Shroud research.

Introduction

In the 1978 STURP testing in Turin, an unusual characteristic of the Shroud image was noted. When viewed from a few feet the image appeared faint but when viewed from a distance the image seemed to be darker relative to the cloth around it; there is an apparent increase in the visual contrast between the macroscopic image area and the pristine cloth as one backs away from the shroud. This paper describes efforts to define and validate an hypothesis for this effect in terms of optical physics. Measurements were made to determine the ratio of reflected light intensity on cloth having a satin finish and a flat finish, and these results were compared with an empirical model used by the computer graphics industry. The results were mixed; some supported the hypothesis and others refuted it. Explanations for these results are provided and a discussion of it's relevance to a possible explanation for the three dimensional quality of the Shroud image.

The hypothesized explanation for the increase in image-cloth contrast with viewing distance lies the physical laws of reflection. The reflected light from any surface can be divided into two components: specular reflection and diffuse reflection. An example of these two extremes is the surface appearance of two samples of the same color house paint; high gloss and flat finish. With high gloss paint, most of the light falling on the surface reflects off at a narrow angle opposite the incoming light angle. With the sun shining on the surface, there is an angle where an observer will be "blinded" by the reflected light. For a flat painted surface, the reflected light is nearly uniform at all observer angles. This is illustrated in Figure 1.

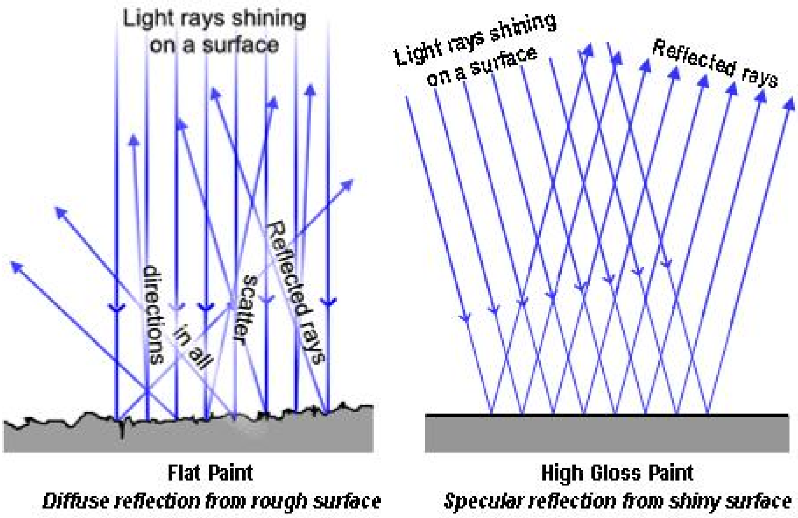


Figure 1. A rough surface scatters light in all directions while a shiny surface reflects the light at a specific angle.

The linen cloth on which the Shroud image appears is of high-quality with a distinct satin sheen in the pristine places where no image, burn marks or water stains are located. However, in the image locations the top surface of the fibers has been degraded and is no longer as shiny. Figure 2 shows the difference between the untouched pristine fibers and those that have been degraded.

Figure 2. The degraded fibers from the image area have lost the sheen characteristic of the pristine fibers.

Hypothesis

Based on the spectral/diffuse reflection theory and the microscope photographs, the following hypothesis was defined:

> *The degraded image area fibers, which have lost the shininess of the pristine fibers, diffusely scatter more light out of the observers field-of-view that do the shiny fibers. As a consequence, as one retreats from the Shroud the ratio between the scattered diffuse image light, which scatters in all directions, and the shiny reflected light from the undamaged cloth, which is concentrated more in the viewer's direction, will decrease resulting in increased image contrast.*

If this hypothesis is true, optical measurements of the light intensity scattered from a rough cloth should decrease relative to the light intensity of a shiny cloth, such as satin, as the measurement distance increases.

Optical Reflection Theory

Specular reflection is what happens when a beam of collimated light hits the face of a front-surface mirror. The incoming light hits the mirror at some angle to the surface normal and all of the reflected beam bounces off the mirror at precisely the same angle but on the other side of the perpendicular normal. However, this ideal case is difficult to achieve because all mirrors have a residual surface roughness that scatters a small portion of the light in a conical angle about the ideal reflection path. Highly polished mirrors can reduce this scattered component to negligible levels for most applications.

To understand the relationship between diffuse and specular reflection, imagine a mirror for which the magnitude and scale of the surface roughness is allowed to increase from negligible to the point where the mirror surface is “frosty”. As the roughness increases, the conical angle of the scattered light will get larger. Since the total reflected light is constant, the amount of light in the specular beam will decrease and the sum of the light scattered into the ever increasing conical angle will increase. In the limit, if the mirror surface becomes perfectly frosty, the light will scatter throughout a hemisphere and no light greater than the diffuse background will appear at the specular reflection angle. This thought experiment demonstrates that diffuse and specular reflections occupy the extremes of a continuum, with all intermediate values being a combination of specular and diffuse components. Figure 3 illustrates a general example of the intermediate case.

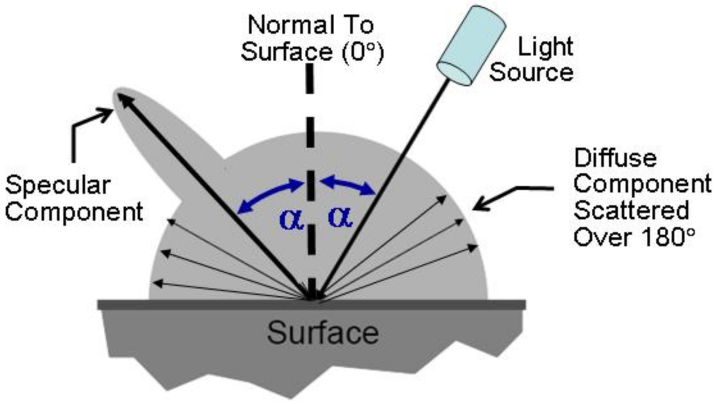


Figure 3. In the general case, most reflections include both specular and diffuse (scattered) components.

Experiment

In at attempt to validate the hypothesis, a set of experiments was devised to measure the relative intensity of light reflected from cloth samples as a function of incoming light angle, light receiver angle, and distance from cloth. No samples of linen cloth with characteristics similar to the Shroud could be found so polyester satin was used. One side of the cloth had a satin sheen while the other side appeared flat with no sheen. The cloth was cut into two samples which were mounted side-by-side in a frame. One sample had the satin side facing front and the other was reversed with the flat side in front.

The geometry of the first two experiments is shown in Figure 4. Received intensity data was taken for selected combinations of source angle and receiver angle. At each location, the cloth frame was shifted from flat to shiny and back several times. The sensor output was recorded for each case and the ratios between the shiny and flat data were calculated.

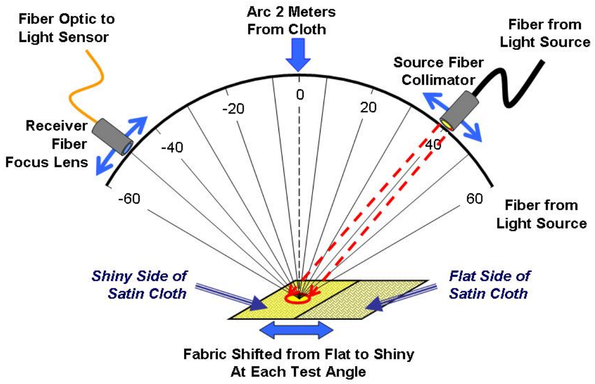


Figure 4. The experimental setup allowed measurements of reflected light intensity from several angles.

The third experiment, measuring the ratios of shiny to flat reflected light intensity, employed the same experimental setup except that the light source was kept 2 m from the cloth at 0° while measurements were taken with the receiver at distances from 2 to 10 m along the 0° line.

Experimental Results

The results of the reflection as a function of source and receiver angle are given in Figures 5 and 6. Below each pair of graphs are the conclusions that can be drawn from the data.

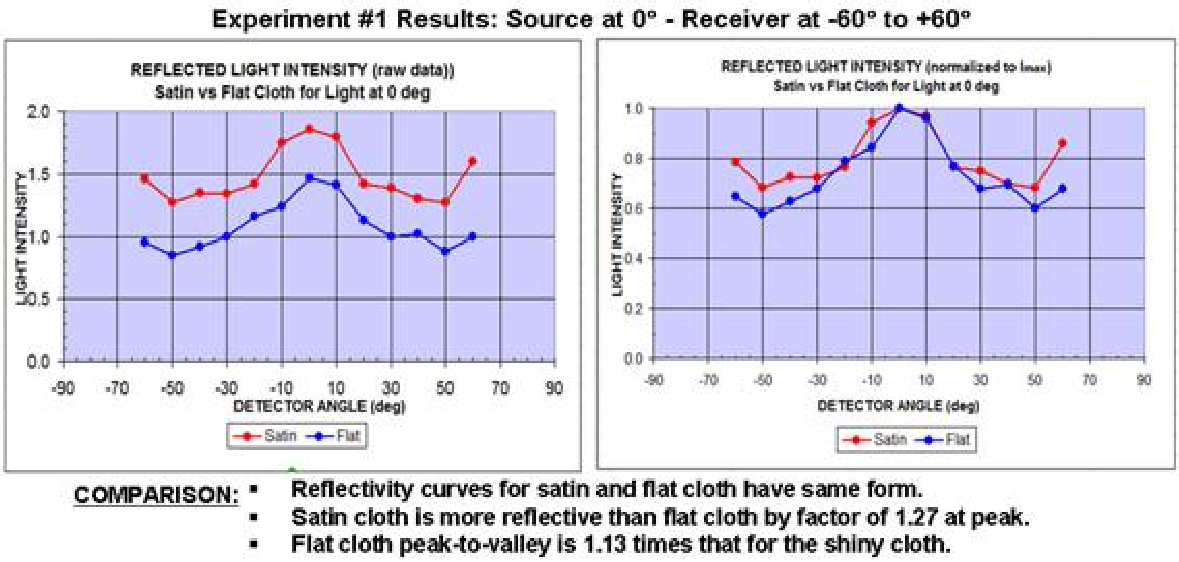


Figure 5. Experimental results with the light source at 0° and the receiver at + and - 60°.

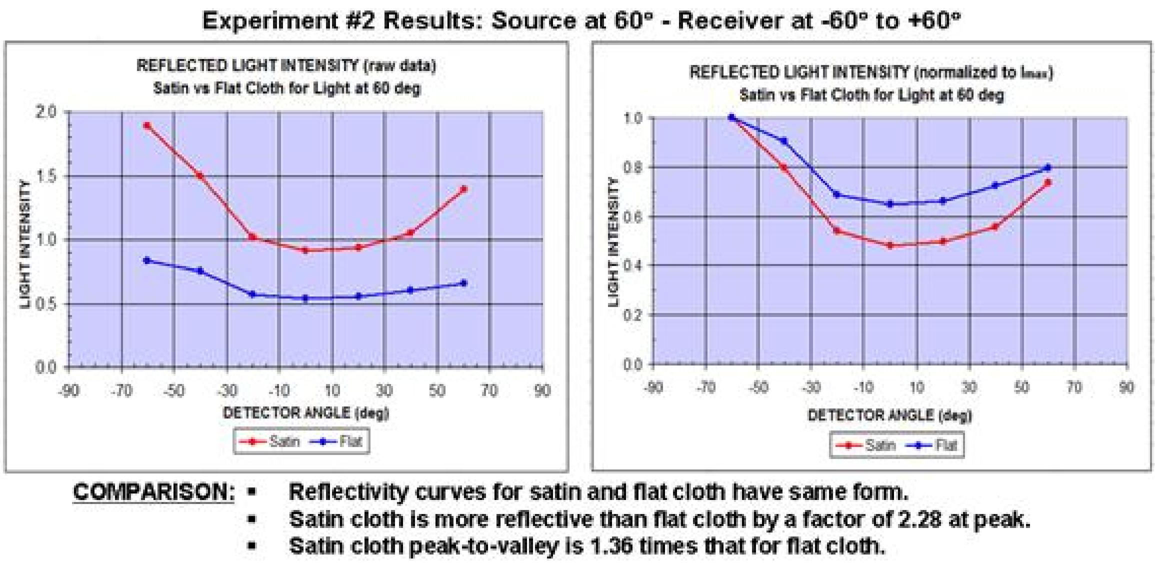


Figure 6. Experimental results with the light source at 60° and the receiver at + and - 60°.

The results of the cloth-to-receiver distance vs. received intensity along the normal are shown in Figure 7.

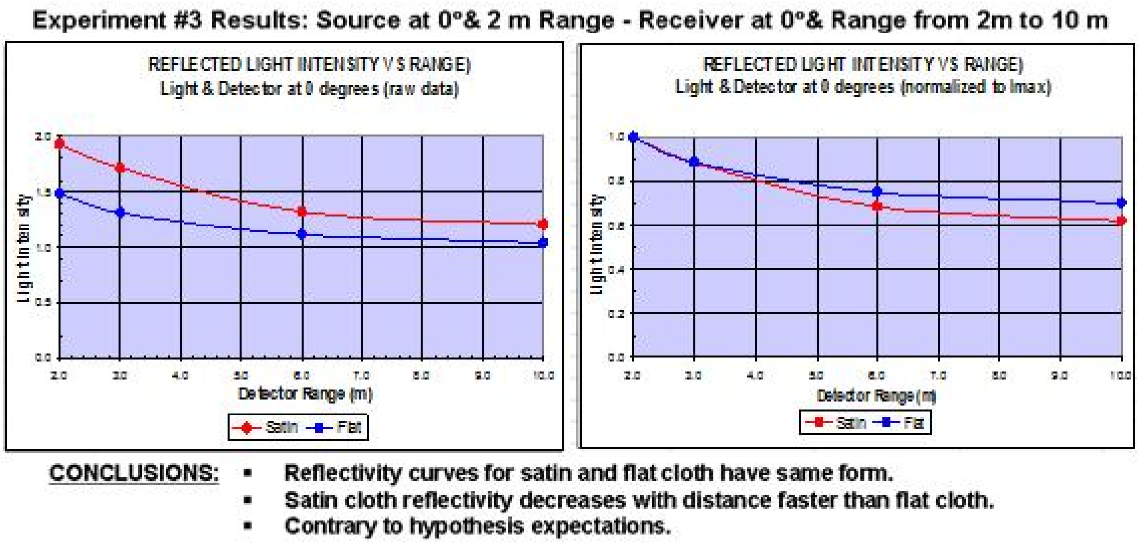


Figure 7. Experimental results with the light source at 0° and the receiver at 0° with the range increasing from 2 to 10 m.

Interpretation of Results

The graphical form of the Experiment #3 results were as expected – a fall off in intensity as the cloth-to-receiver range increased. However, the graphical results for Experiments #1 and #2 have an unusual shape that was not anticipated by the experimenter. After research into how computer graphics artists mathematically represent the shininess of objects, the reason for the curve shapes became clear. The most general model used for this application is known as the Phong model. In this empirical model, the intensity of the light reflected from an object has three components: the reflected ambient light plus the reflected diffuse and specular source light. The details of the Phong model are given in Figure 9.

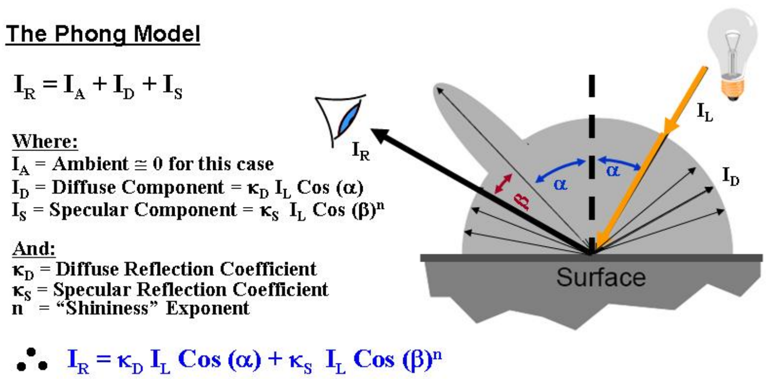
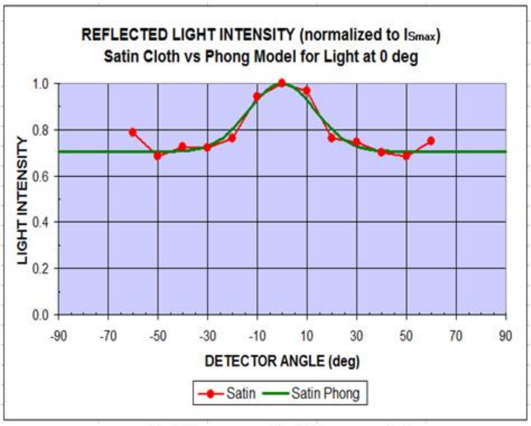
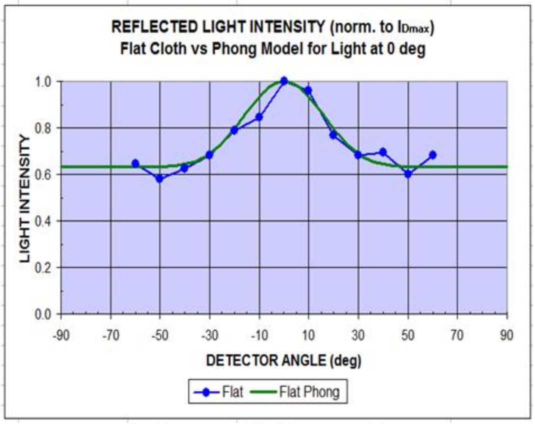


Figure 9. The Phong model provides a mathematical representation of light reflected from an object.

When the Phong model was applied to the geometries of Experiments #1 and #2, the reflection and exponent variables could be adjusted to provide a very close match to the graphical results, as demonstrated in Figure 11.





$\kappa_D = 0.60,\ \kappa_S = 0.25,\ n = 18$ $\kappa_D = 0.12,\ \kappa_S = 0.07,\ n = 13$

Figure 11. The Phong model reproduced the experimental results quite closely with the appropriate selection of variables.

Results and Conclusions

The goal of matching the Phong model to the experimental data was to calculate the ratio of specular/diffuse reflection coefficients that yielded the measured results. These results, along with the Experiment #3 results are given in Table I below along with comments as to their significance.

Table I. Summary of results.

DERIVED PARAMETERS	VALUES	COMMENTS
Satin Cloth K_S/K_D	0.42	Larger ratio for flat cloth implies it has relatively more specular component than satin cloth. Counter to intuition and hypothesis.
Flat Cloth K_S/K_D	0.58	
n_{SATIN}/n_{FLAT}	1.38	Larger exponent for satin implies higher specular component. Agrees with intuition and hypothesis.
Satin Specular Divergence Angle	32°	Identical specular divergence angle for satin and flat is contrary to intuition and perhaps the hypothesis.
Flat Specular Divergence Angle	32°	
Specular/Flat Intensity @ 10m Range	0.89	Lower relative specular intensity at range is directly contrary to hypothesis.

The calculated ratio of the specular/diffuse reflection coefficient ratio should be higher for a shiny cloth. In this case the diffuse reflection coefficient ratio is higher, which seems contrary to intuition – one would expect a shiny satin cloth to reflect more light back at the receiver relative to the diffuse reflection than a flat cloth. It also does not support the original hypothesis because the hypothesis requires the shiny pristine cloth to direct more light towards the viewer. The ration of the shininess coefficients, however, does agree with both intuition and the hypothesis because the satin cloth is shinier that the flat cloth.

The Phong model includes an angle term, β, that specifies the distribution width of the specular component. For a shiny material, one would expect this angle to be narrower than for a flat material. In this case, both materials had equal values for β. Although the hypothesis doesn't directly require that the specular angle be larger, a narrower specular angle would clearly enhance the hypothesized contrast increase with range.

The final result to examine is the relative decrease of the satin and flat reflected intensity with increasing cloth-to-receiver range. As seen in Figure 7, the measured reflected intensity is lower at all ranges for the flat cloth, which would seem to agree with expectations. However, when the two sets of data are normalized to a maximum value of 1.0 we see that the reflected intensity from the satin cloth sample decreases faster with range than does the flat cloth reflection. This is directly contrary to the hypothesis and, if generally true, would result in the pristine cloth getting darker with range compared with the image area reflection.

The bottom-line conclusion from this work is that the results do not confirm the hypothesis. There are several possible reasons for this, which are listed below.

- *The experiments and cloth samples did not accurately represent the conditions of the actual Shroud of Turin.*
- *The Phong model is not well suited to simulating the reflection from cloth material. (Indeed, there are several highly complex models that graphics designers use for creating realistic cloth graphics.*
- *The hypothesis is incorrect and there is some other optical effect that is the basis for the observation.*
- *The observation of the effect when viewing the Shroud is an optical illusion and not founded in optical physics at all.*
- *The reflection of light from cloth is a more complex process than can be described with the relatively simple Phong model.*

Although understanding the observed effect has little known relevance to other areas of Shroud research, the work presented here might serve as a starting point for a future researcher who may discover that the effect does indeed have relevance to understanding other characteristics of the Shroud; perhaps even the 3-dimensional quality of the image.

Thoughts On the 3-Dimensional Image

As a closing comment, the fact that the image possesses a 3-dimensional nature is not surprising at all from an optical physics standpoint. The image is 3-D because it is darker in areas that touched or were closer to the body surface. *This is not speculation, it is a photographically demonstrated fact.* One has only to postulate a mechanism that makes the image in those areas darker. Since it was established by the 1978 STURP results that the "darkness" is due to degraded fiber surfaces, all that is required to create a 3-D effect from this is a variation in the density of the degraded fibers for those areas in closer proximity to the body the cloth was laid on. (This is exactly how shades of grey are printed; darker shades have a higher density of dots.) As can be seen in Figure 2, not all the fibers in a given image area are degraded; there is a mix of unaffected fibers with the degraded ones. An analysis of the 1978 STURP microphotography results might determine if the ratio of damaged to undamaged fibers increases for darker image areas.

One explanation for this degraded fiber density variation would be that the cloth was in contact with the high points of the body longer than it was for the lower areas. In an experiment conducted in 1980, the author laid a fresh piece of linen over a life-sized human facial bust and placed it in a humidity chamber. Over the next 12 hours, the linen slowly drooped into lower and lower areas of the facial contour until it was in contact with all but the smallest crevices. If this scenario happened with the Shroud, as one might expect with a cloth covering a dead body slowly giving up moisture, then the high points of the body would be in contact with the cloth for a longer time, giving the body fluids exuded during the torture and crucifixion more time to seep into more fibers and fibrils. This is quite a simple and plausible explanation that could easily be tested by a young, energetic "third wave" researcher.

One final thought on the "impossibility" of making a photograph that has 3-D qualities: it is not impossible, or even very difficult. If a front-lighted facial portrait is taken in a chamber where a uniformly distributed, moderately dense grey or black "fog" is present, less light will reach the receding portions of the face due to absorption of the light by the fog. Furthermore, of the light that does reach the more distant parts of the subject, more of the reflected light necessary to make the photograph will be absorbed on the way back to the camera, increasing the distance-dependent contrast even more.