The Hemispherical Receptor Incident Light Exposure Meter

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ABSTRACT

Incident light exposure metering is a useful technique for planning photographic exposure in many situations. An important genre of incident light exposure meter uses a hemispherical receptor. While there are various facile explanations of what this formulation does and why that is beneficial, the underlying technical concepts are elusive.

In this article I give a concise overview of the basic operation and premises of this type of meter. Some basic background in the concept of incident-light exposure metering is provided.

1. Preface

The material in this article is for the most part drawn from the companion article by the same author, "The Secret Life of Photographic Exposure Metering", probably available from the same place you got this.

It places this topic in a broader context of exposure metering and gives much further technical detail. Readers interested in such are commended to that article.

2. Exposure planning

2.1 Our objective

Before we can look into ways to plan photographic exposure, we must be able to articulate what we want in the result. One widely-cited objective (on which we will focus here for a while) can be described thus (in a digital image context):

> Objective B: In the final image, the implied relative luminance of each scene element should correspond to the reflectance of that element. [1] [2]

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[1] The significance of the "B" is to fit in with other writings in which I describe another objective as Objective "A".

[2] This is closely related to the underlying premise of the famous "zone system" of planning photographic exposure.

A popular way to describe one of the implications of this objective is that, if the objective is attained:

- For a shot of a white cat on a snowdrift, the image will look like a white cat on a snowdrift.
- For a shot of a gray cat on an ash heap, the image will look like a gray cat on an ash heap.
- For a shot of a black cat on a coal pile, the image will look like a black cat on a coal pile.

2.2 A fly in the ointment

A complication is that we cannot possibly attain that objective if the illumination is not essentially uniform from all directions. Often is it not (and in fact in just a little while we will look into a reason we may intentionally make it substantially non-uniform).

But for now we will press on as if that objective can be attained.

2.3 Exposure planning to attain that objective

If in fact the illumination on our subject is uniform from all directions (meaning, to be technically precise, that the illumination would give the same *illuminance* on a subject surface of any orientation), then (regardless of the fact that various elements of the subject surface face in different directions) that objective can be attained.

We can actually do that by using a photographic exposure (that is, a combination of shutter speed and aperture) that is based in a fixed way on that consistent illuminance (and of course the sensitivity of the film or digital sensor).

We can handily determine that illuminance with a "basic" incident light exposure meter, one that actually measures the illuminance on the plane of its receptor.[3] And, since at this point we assume a directionally-uniform illumination, we can orient the meter any way we like.

3. Key-fill lighting

3.1 Description

An important lighting technique, often used in cinematography and also in portrait and "fashion" still photography, uses two light sources. One, the "key light", is the primary source. It is placed to illuminate the subject from some direction chosen by the photographer to get the

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[3] Such a meter can be described as having a *cosine response*. Its response to a light beam of a certain potency, arriving at a certain angle, is proportional to the cosine of that angle.

desired "sculpting" of the subject (by way of shadowing by the subject's features). It is commonly directed toward the subject from an angle of 30°-60° from the camera axis (on one side or the other).

The second source, the "fill light", is usually of less "potency" (to use an intentionally unscientific term), and is typically directed at the subject from the camera position. Its job is basically to "dilute" the sculpting so the desired artistic effect is attained.

We often describe the particular arrangement use in terms of the ratio between the "potency" of the two light sources (sometimes described as the "contrast ratio", a term that is not particularly apt). This is actually in terms of the ratio of *luminous flux density* of the two beams as they arrive at the battle zone. But is it more often described (imprecisely) as the ratio of the *illuminance* of the two beams, actually meaning the illuminance they would cause on a surface directly facing the respective source.

Commonly-used ratios (key:fill) range from 1:1 to 8:1.

This is of course a non-uniform illumination situation.

3.2 Exposure planning in this situation

Here we have intentionally provided a substantially non-uniform illumination, and so of course we cannot hope to attain Objective B. So we must adopt some other criterion for the result we hope to attain by our choice of photographic exposure.

In the absence of any objective criterion for the result, we cannot hope to address the question, "what kind of incident light exposure metering technique will recommend the 'proper' photographic exposure in a key-fill lighting situation".

Many empirical techniques have been suggested, such as to perhaps use an "illuminance-responsive" incident light meter to take two readings, one with the meter receptor facing the key light source and one with it facing the camera (and thus perhaps the fill light source) and somehow make an exposure determination from those.

This was not considered handsome by professional cinematographers and photographers, both because it was clumsy and because it did not necessarily give the "most appropriate" photographic exposure recommendation (meaning that this did not consistently lead to a "desirable" overall exposure result, whatever that would mean).

4. The hemispherical receptor meter

4.1 Introduction

In the late 1930's, noted cinematographer Donald W. (Don) Norwood, well aware of the problem of conveniently determining the optimum photographic exposure in a key-fill lighting situation, introduced a new type of incident light exposure meter. In its first form, this had a photoreceptor that had the shape of a hemisphere.

In the intended use of such a meter, the hemispherical "dome" is always "pointed at" the camera, regardless of the lighting arrangement, and a single reading taken.

Later, in order to reduce the cost of manufacture, Norwood developed an alternative implementation, using a translucent hemispherical shell at the base of which was a classical flat photoreceptor.

Soon, this type of meter became *de rigeur* for professional cinematographers and photographers, and that product trail continues to this day, as seen most prominently in many exposure meters made by Sekonic, eventual successor to the rights to the Norwood patent.

In figure 1, we see a Norwood Director, Model B exposure meter (made by American Bolex, *ca*. 1948), in this particular livery probably the most beautiful exposure meter of all time.

Figure 1. Norwood Director exposure meter, Model B

Image © James Ollinger

4.2 How do it know?

We can readily predict the angular response of a hemispherical receptor meter. With that in hand, it is tempting to try and develop a mathematical model that will show why the reading of such a meter would be a good determinant of the "optimum" photographic exposure over a range of subject configurations and lighting situations.

But such a quest is doomed, at best, in part by the fact that there is no clear criterion as to what exposure result is "best". (Recall that we cannot just say "attain Objective B", because that cannot possibly be attained in the general case of non-uniform illumination.)

Several facile explanations of how this meter do that *voodoo that it do so well* begin with the notion that "[the meter is] substantially uniformly responsive to light incident upon the photographic subject from practically all directions which would result in the reflection of light to the camera or other photographic register."[4]

But although that sounds nice, and is correct, it doesn't really explain why the resulting meter reading is a good determinant of the most appropriate photographic exposure in non-uniform illumination situations.

A later explanation by Don Norwood tells us that the hemispherical receptor is a proxy for the visible-to-the camera portion of a human head (a subject that is certainly a preoccupation of fussy lighting planning). Some analysis leads us to realize that the reading of a hemispherical receptor meter approximates for us the average illuminance over the camera-visible surface of such a subject. That at first sounds like a telling parameter from which to determine the proper photographic exposure.

But as we try to build **that** into some model as to why that parameter should be the determinant of the most appropriate photographic exposure, it doesn't come together. For one thing, if we use a hypothetical uniform-reflectance subject to help us follow the "photometric trail", we find that the average illuminance on the subject is not a good predictor of the average luminance seen by the camera.

And of course, as before, another stumbling block is that we cannot describe, for a case of non-uniform illumination, a good criterion of the "appropriateness" of exposure result.

4.3 Aha!

In 1950 (well, it was about time!), Norwood published a paper ("Light Measurement for Exposure Control", *J SMPTE 1950, 54:585-602*) that presented a credible, albeit empirical, rationale for the working of the hemispherical receptor meter.

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[4] Cited in fact from Norwood's original patent on the hemispherical receptor meter.

In it, he described the results of tests in which human observers compared a shot of a certain subject taken with a "head-on" key light with a shot of the same subject taken with a key light (of consistent potency) at a certain angle to the side, for various angles. All shots included the use of fill light (at a ratio of 8:1, key to fill).

The exposure used for the "head-on" shot was based on incident light measurement of the actual key+fill illuminance on the camera-facing plane, using the generally-accepted incident light metering equation.

For each key light angle, a number of shots were taken with various increments of photographic exposure greater than that used for the head-on shot. For each series of shots, the observers were asked which side-lit shot "matched in appearance" the head-on shot.

> Whatever that meant. Clearly they would not "look the same" since the "sculpting" would be quite different. We must assume that what Norwood meant was that the shots "matched in the impression of overall exposure result", or some such notion.

Statistical analysis of the test data led Norwood to the conclusion that, over the range of subjects used, the photographic exposure required for the side-key shot to get visual parity with the head-on key shot was, on the average, greater than the photographic exposure for the head-on key shot by the amount shown in column 2 of this table:

1. Key light angle (degrees)	2. Needed additional exposure (stops)	3. Implied relative effective illumination	4. Relative reading of hemispherical receptor meter	5. Relative reading of cosine pattern meter
0	0	1.00	1.000	1.333
45	*0.42* *	0.75	0.870	0.986
90	1.00	0.50	0.566	0.148
135	2.00	0.25	0.146	0.148

* Shown in the paper as "0.50 –"; the value in this table is back-formed from the exact value of *implied relative effective illumination* given in the paper.

Column 3 shows the implication of the needed additional photographic exposure "the other way up", as a declining "relative effective value" of the illumination offered by the combination of the two light sources, the response of 1.00 at 0° being by definition.[5]

[5] The cynical reader may marvel that, in the face of such a highly subjective observation, the statistical result led to such tidy values of the relative effective illuminance at these angles, forming a perfectly linear progression with angle.

Therefore, if we wished to have a meter that would automatically call for, in its exposure recommendation, the additional exposure needed for side key lighting, then its relative reading, from both key and fill light, should ideally equal the value in the column 3.[6]

The theoretical relative reading of a hemispherical receptor meter (responding to both key and fill light) is shown in column 4. We see that this is in modest agreement with the "requirement" in column 3.

Thus we can expect a hemispherical receptor meter to give us a generally-good exposure recommendation for key-fill technique over a range of key light location angles.

To give a small snipe, I note that in Norwood's paper he says:

- The sensitivity pattern of the meter should ideally match column 3. (In fact, it is the meter "reading"— its response to the combination of fill and key light—that should match column 3.)
- The theoretical sensitivity pattern of a hemispherical receptor meter would exactly follow the values in column 3. (In fact, as we will see shortly, the theoretical sensitivity pattern is not the "linear decline with angle" implied by that statement.)

These discrepancies are small, numerically, and do not disrupt the point being made, which in fact does not depend on any precise theoretical concept.

In column 4, to "close the circle", we show the expected relative reading of a cosine-pattern (true illuminance) meter, with its receptor facing the camera and fill light. Here, I have assumed that, as is industry practice (and implied by the ISO standard), the 0° sensitivity of the cosine meter is 4/3 the 0° sensitivity of the hemispherical-receptor meter.

4.4 Other lighting situations

Norwood's 1950 paper presented a persuasive and easily-followed rationale for the well-known good performance of the hemispherical receptor meter in the very important key-fill lighting situation.

But what about other non-uniform lighting situations? Will such a meter provide consistently "good" photographic exposure indications there? And in fact what criterion would we use to judge "success" there? And can we formulate some model that will show why that success is attained?

I leave the judgment of the practical success of such meters in the general case to photographers that regularly use them.

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[6] Note that this is not the desirable value of the sensitivity of the meter at those angles; both key and fill light are involved here each at their own angle.

As to a theoretical model that shows how that comes about, given the lack of any accepted objective criterion of "success", and many other impediments, the quest for such a model would be a fool's errand.

5. The sensitivity pattern of a hemispherical receptor meter

5.1 Introduction

I had earlier noted that for an exposure meter to respond to the illuminance of the incident illumination (as defined upon a plane of some particular orientation), we would need a meter with a "cosine" sensitivity pattern.

In figure 2, we see a plot of such a pattern, in both polar coordinate and rectangular coordinate forms.

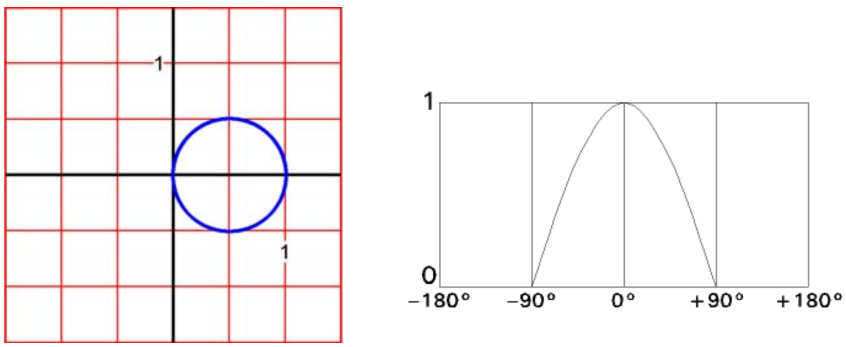

Figure 2. Cosine sensitivity pattern

If we derive the theoretical sensitivity pattern of a hemispherical receptor meter, we find that in polar coordinate presentation it exactly follows a curve known as a *cardioid*.[7] (A proof of this is given in the companion article.)

In figure 3 we see a polar plot and a rectangular plot of a cardioid sensitivity pattern.

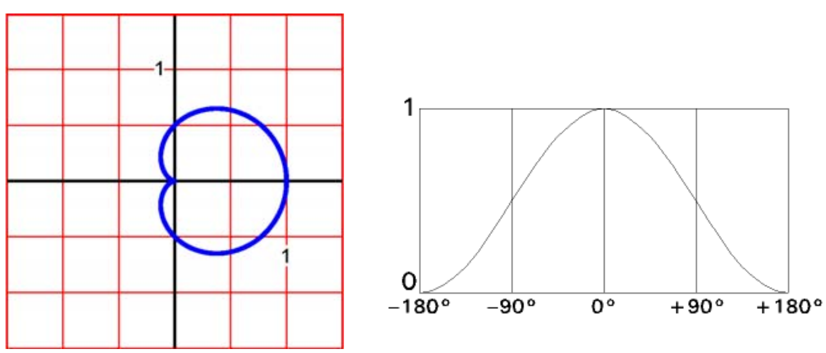

Figure 3. Cardioid sensitivity pattern

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[7] The name, from the Latin, means "having the form of a heart". The allusion here is to the kind of "heart" we see on greeting cards.

6. CONCLUSION

The hemispherical receptor concept of incident light metering, introduced by Norwood, has been shown to be a valuable tool in cinematographic and photographic exposure determination. We should not look to any objective theoretical models to explain that success.

7. ACKNOWLEDGMENT

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