TONE AND COLOR CONTROL IN DUOTONE REPRODUCTION

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Abstract: When duotones are made arbitrarily, their success depends largely on chance, if not on costly remakes. In this paper, the point is made that good duotone reproduction can be attributed primarily to proper tone reproduction and desirable color rendition. These two subjective criteria can be expressed graphically for a given original copy when materials, i.e., inks, paper, press, etc., are specified. Operationally, a duotone chart is devised to solicit specific printing conditions. Further, these two duotone criteria can be translated into halftone requirements by an analytic method. The strategy of the method is given. Halftone operations using the halftone exposure programming for three-point control are explained. Duotones made with various ink combinations are discussed. The significance of the method is that duotone qualities can be predetermined graphically and accessed analytically from the defined criteria.

Introduction

In image reproduction - by whatever means this is accomplished - the relationship between original and reproduction has always been a central issue. The debate has centered on tone reproduction as a measure of quality. For the moment considering just monochrome reproduction, the consensus seems to be that if the reproduction can be made with the same tone range as the original (same end point densities, same density range), then a facsimile straight line 45-degree tone reproduction is preferred. But, if the reproduction process is limited by, for instance, a maximum solid ink density lower than the maximum density in the original, then we have the question of either reducing all tones in the original the same proportional amount, leading to a lower than 45-degree but still straight line tone reproduction, or bend the tone reproduction curve to suit the "keyness" of the image.

In duotone reproduction if the facsimile reproduction criterion holds, then its success depends on the proper selection of an ink combination to best match the color rendition characteristic of the original copy and a 45-degree straight line tone reproduction curve. Most frequently, the duotone reproduction process is utilized as a reproduction means as well as a creative process in graphic arts industry. For the reproduction aspect of the duotone process, it often means a longer reproduction range and thus, better reproduction quality when compared with a monochrome process. On the other hand, the creative aspect of the duotone process often means the effective use of the two impressions, usually in a color/black ink combination, to create a particular mood suitable to the subject matter in the scene.

If we set out to reproduce pleasing duotone reproductions, we have to exercise certain controls in the process such that the two important criteria, i.e., proper tone reproduction and desirable color rendition can be fulfilled. To approach this goal, we first need to define qualitatively the meaning of tone reproduction and color rendition; and then, we need to express them objectively so that a method can be devised that will provide quantitative data for tone and color control in the process. This paper has the above objective. To avoid possible complications in reproducing duotone illustrations in this proceeding, the intent of the paper is to give a brief report on how to use the method and ideas behind the method. A more elaborate report containing various duotone illustrations will be given in a separate GARC/RIT Research Report.

Duotones vs. Cocktails

The word, duotone, is nebulous to many people. It seems appropriate that we should start out with a close examination of this word. The word, duotone, is treated as a general term in this paper. It is

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like the word, "cocktail", a term used to describe various mixes of alcoholic ingredients. However, if we specify the materials used in the duotone process, i.e., ink combination, paper, press, etc., then we are dealing with a specific duotone process. This is analogous to the mixing of gin and vermouth, the combination of alcoholic ingredients known as a "martini". In other words, duotone is a photo-mechanically oriented term which is characterized by its two superimposed impressions and a distinct screen angling difference between the two halftones. The possible ink combinations: color/black, black/white, or color/color, make the duotone process more diversified. By the same token, who would mind a variety of cocktails as long as they are tasteful.

Background and Strategy forFulfilling the Duotone Criteria

Although the concept of tone reproduction has been studied extensively for monochrome and four-color reproduction processes, this has not been the case with the duotone process. Reasons for such a delay may be attributed to (1) duotone ink combinations are so arbitrary that efforts in assessing duotone characteristics under a given printing condition are enormous; (2) the expression of color rendition characteristics for a duotone image is implicit. Consequently, the state-of-the-art of the duotone reproduction process has remained largely at a trial and error stage. Nevertheless, technological advances in halftone exposure programming as well as knowledge gained through tone reproduction studies are two important resources to this study. They have provided a solid background and made the proposed method viable. We shall have more to say about applications of these advancements in later sections.

In a preliminary exploration, a duotone chart was devised and found to be useful as a diagnostic tool for soliciting duotone information. Figure 1 shows a schematic diagram of the duotone chart. In essence it consists of two halftone scales situated 90-degrees apart in its step orientation and 30-degrees apart in its screen angling orientation. For convenience sake, we shall designate the horizontally incremented scale as the first

Figure 1. Schematic diagram of a duotone chart.

impression and the vertically incremented scale as the second impression. Each impression samples a full range of tones from those equally incremented halftone steps for each given ink. As the dot area value increases with respect to its step number, this geometric arrangement puts duotone highlights at the lower left corner and duotone shadows at the upper right corner of the duotone block. Therefore, a printed duotone chart shows qualitatively duotone characteristics for a specific set of printing conditions, i.e. ink combination, paper, press, etc.

Let's consider the specification of color rendition characteristics first. Using Figure 1 as an example, if we print the first impression with a color ink and the second impression with
a black ink, then we can visualize various color rendition paths between the highlight (lower left) and the shadow (upper right). For example, the color rendition curve that extends counter-clockwise from the highlight to the shadow looks more color predominant than the curve that extends clockwise. This suggests that the duotone chart can be used as a color communicator whereby a subjective color rendition choice can be specified. Moreover, such a color rendition choice should be objectively expressed so that its effect can be incorporated into the duotone reproduction. To accomplish this, let's consider that every duotone patch is a combination of two superimposed impressions with known film dot area values. This would allow us to express a color rendition curve graphically in a dot area vs. dot area coordinates, hence, a duotone diagram. Figure 2 shows a color rendition curve in a duotone diagram.

Figure 2. A color rendition curve specified in a duotone diagram.

Next, the specification of tone reproduction characteristics. As a review, a tone reproduction curve, in its graphical form, shows the tonal relationship between the reproduction and the original. For example, the terminal point of the tone reproduction curve, as shown in Figure 3, represents quantitatively the shadow of the duotone reproduction and of the original copy.

Notice that tonal values of the highlight and the shadow in the original are measurable from the original itself; their corresponding values in the reproduction are also measurable from selected patches in the duotone chart. This leaves the shape of the tone reproduction curve to be determined.

The subjective sensation which we call proper tone reproduction correlates with the shape of the tone reproduction curve for a given original copy. Because tonal values can be expressed in various units, e.g., density, brightness, Munsell lightness, etc., a preferred tone reproduction curve shape is also coordinate dependent. In Figure 3, the shape of the tone reproduction curve is slightly S-shaped in density coordinates. However, it will be transformed into a straight line in Bartleson-Breneman brightness coordinates. Such a curve shape is recommended in many tone reproduction studies because it tends to yield optimum reproduction quality (Archer, 1979 and Jorgensen, 1975). Hence, by utilizing knowledge gained through tone reproduction studies, the tone reproduction criteria can be favorably specified in a graphical form for further manipulations.

Up to this point, we are able to specify the two duotone criteria graphically. The next step
is to devise a method such that the two criteria can be converted into some operable parameters such as density and dot area for halftone operations. In the following we shall illustrate how and why the proposed method can provide the linkage between the duotone criteria and the halftone operation.

One of the ideas behind the proposed method is that duotone patches of the same visual density can be produced by different pairs of halftone tints. Such an equal visual density response as seen by a densitometer can be expressed as an isodensity line in a duotone diagram. If we measure enough duotone patches and record their visual density values, we can generate a series of isodensity lines with the aid of a computer program. Briefly, the program input consists of percent dot area values of each step in the halftone scale and a matrix of visual density values of those duotone patches. The program itself is primarily a looping procedure whereby the mathematical linear interpolation formula is used repeatedly for output calculations. Finally, the program output is a tabulation of percent dot area pairs of the two impressions for all specified visual density values. When these data are plotted in a duotone diagram, as shown in Figure 4, the series of isodensity lines becomes a graphical representation of the printed duotone chart. It is also the backbone of the method whereby the two duotone criteria are interacted and halftone requirement are deduced.

**Procedures for Finding Halftone Requirements**

**With the Three-point Control Algorithm**

To describe the procedure of making a duotone reproduction having the specified duotone criteria, we shall consider the three-point control algorithm in the halftone operation. In the two-step analysis method, let's consider the tone reproduction criterion first. To be specific, the three points \((H, M, S)\) represent the control patch at highlight, mid-tone, and shadow of an original copy respectively. In terms of coordinates of these points in a tone reproduction diagram (see Figure 5), \(D_H, D_M, D_S\) represent their density values in the original stage; \(d_H, d_M, d_S\) represent their density values in the reproduction stage. As mentioned

**Figure 4.** A series of isodensity lines, expressing visual densities as a function of dot area values of the two halftone impressions in a duotone diagram, is a graphical representation of the printed duotone chart.

**Figure 5.** The three-point control algorithm is used to express the tone reproduction characteristics in halftone operations.
earlier, the two end points of the tone reproduction curve are constructed by measurements made from the original copy and the duotone chart; the shape of the tone reproduction curve is constructed by utilizing knowledge gained through tone reproduction studies. Thus, the outcome of the first step analysis is specifications of the three control points, i.e., \((D_H, d_H), (D_M, d_M),\) and \((D_S, d_S)\) via the tone reproduction curve. In turn, the three reproduction densities \((d_H, d_M, d_S)\) can be expressed as three isodensity lines in a duotone diagram as shown in Figure 6.

![Figure 6](image)

Figure 6. The graphical solution whereby the two duotone criteria are interacted and halftone requirements are deduced in a duotone diagram.

The second step of the analysis is to specify the color rendition criterion. To recap, the subjective color rendition is first visualized with the use of the duotone chart, and it is then expressed graphically in a duotone diagram. In doing so, the color rendition curve intersects with the three specific isodensity lines as illustrated in Figure 6. Consequently, the three intersecting points, each providing a pair of dot area values, are outcomes of the second step analysis where \(H_1, M_1, S_1\) denote dot area requirements for the three control patches of the first impression, and \(H_2, M_2, S_2\) denote those of the second impression.

By specifying density values of the original \((D_H, D_M, D_S)\) and dot area values of the halftone \((H_1, M_1, S_1\) or \(H_2, M_2, S_2\), a halftone exposure program, such as the one put out by RIT, may be used to calculate main, bump, and flash exposures so that the three defined dot areas are placed at the corresponding control patches in the halftone operation (Archer, 1977).

As summarized in Figure 7, the first step in the analysis process fulfills the tone reproduction criterion, and the second step fulfills the color rendition criterion. The result of this two-step analysis provides essential data for halftone operations. Upon printing the two halftone images, we then achieve the duotone reproduction which possesses the defined duotone characteristics.

![Figure 7](chart)

Figure 7. A flow chart with the three-point control algorithm shows how duotone criteria and halftone requirement are related by the two-step analysis method described.
Considerations for Duotones Made With Different Ink Combinations

While quality of the duotone reproduction can be affected by many production variables, its visual appearance is primarily affected by the ink combinations chosen. From the chromatic viewpoint, inks can be divided into two categories, i.e., black inks and color inks. Since any two inks can be used to print the duotone, we will have three ink combinations to deal with. They are color/black, black/black, and color/color combinations. Each of the three ink combinations is unique with respect to the color rendition criterion. They are generally alike with respect to the tone reproduction criterion. We shall discuss each of them briefly in the following.

Let's consider duotones in color/black ink combinations first. It is advantageous to choose a saturated color ink to start with. For example, an orange ink is preferred to a brown ink because brown colors, in effect, are dark shades of orange. Thus a saturated color ink, when printed with a black ink, provides more color rendition capabilities than a desaturated color ink. In terms of the tone reproduction criterion, we may consider the overall tone reproduction as made up of two partial tone reproduction curves of the color/black impressions. In Figure 8, an orange ink is used as the color ink. Notice that the visual density of the orange $D_{max}$ is relatively low when compared with the black $D_{max}$. Nevertheless, the degree of color predominance of the duotone image is determined by the saturation of the color ink as well as the color rendition curve chosen. On the other hand, we may consider that the overall tone reproduction curve is achieved by the black impression which takes into account the partial tone reproduction contribution of the color impression.

Next, duotones that are printed with a black/black ink combination. It is generally recognized that duotone blacks are suitable for high quality reproduction of black-and-white original copies. This is because it suffers less and, sometimes, no tone compression from the tone reproduction viewpoint. As far as the color rendition is concerned, the color rendition curve for duotone blacks is path-independent since there is no color involved. However, the physical shape of the color rendition curve suggests how the two black impressions are to share their responsibilities to fulfill the overall tone reproduction requirement. In particular, if the "color" rendition curve is a 45-degree straight line, then halftone exposure requirements for both black printers would be identical. Such an arrangement is useful because it simplifies halftone operations.

In addition to the high $D_{max}$ advantage we have mentioned earlier, duotone blacks also offer a greater tone reproduction curve-bending capability than a monochrome reproduction process. Figure 9 shows typical examples of various tone reproduction curves the duotone blacks offer: Curve A (straight line) is favorable for reproductions of scenes with normal tone distribution, Curve B (bowed upward) is recommended for reproductions of high key subjects and Curve C (bowed downward) for low key subjects. The somewhat unusual Curve D (reverse S-shaped) provides less midtone contrast in the reproduction with enhanced highlight and shadow details.

![Figure 8. The overall tone reproduction curve is made up of two partial tone reproduction curves in a duotone process.](image-url)
duotone analysis method should be equally adaptable for other applications made with color/color ink combinations.

Discussions

Going back to the cocktail analogy. When we are mixing a particular cocktail, in a sense, we know which bottles to choose but we don't necessarily know how much to pour from each to obtain the best taste. This argument seems to be applicable to a duotone process. Normally, the tone reproduction criterion is weighed more than the color rendition criterion. Using the prescribed method, we can reproduce duotones made from the same original copy, to have the same tone reproduction response but have different color rendition responses, and vice versa. In other words, the prescribed method serves as a jigger that allows us to manipulate the mixture of the two impressions for best visual results.

Various "exposure techniques" have been mentioned in many journal articles for achieving certain duotone effects. While the meaning of exposure techniques is implicit, its effect is dependent upon too many variables in a duotone process. These variables include material-related ones (film, camera, screen, chemistry, etc.) as well as original-related ones (copy contrast, scene type, etc.). Consequently, justification for using any one of these exposure techniques relates to the specific conditions. On the other hand, the two duotone criteria, suggested in this paper, are exposure independent, i.e., the choice of the tone reproduction and the color rendition characteristics, say by art directors, is not directly related to the halftone exposure requirement. Thus, it would allow a greater degree of freedom to non-production personnel for their artistic inputs. Only production personnel need to know how to translate the two criteria into exposure-related data under his own production environment. With the above considerations in mind, it is believed that we now have a better approach in dealing with the control of tone and color in duotone reproductions.

Finally, duotones that are printed with color/color ink combinations. The visual effect of color/color duotones can be quite attractive when the ink combination is carefully chosen. One interesting application for duotones of this type is to simulate the four color reproduction effect. For example, if we choose a set of complementary color inks, say red and green, the duotone effect may be suitable for reproducing color originals in which hues in the scene are predominantly red and green. In terms of duotone criteria, the tone reproduction consideration remains unchanged, but the color rendition criterion should be modified to suit the gray balance requirement known from four color reproductions. To be specific, we can trace a neutral or near-neutral color rendition path in the duotone chart. This is possible when using a set of complementary color inks. If we select such a path as the color rendition criterion, then the gray balance requirement can be fulfilled nicely. While this particular application has been experimented and found satisfactory, the
Conclusions

We have pointed out that proper tone reproduction and desirable color rendition are two subjective criteria for pleasing duotone reproductions. These criteria can be expressed graphically and linked analytically by the prescribed method. The outcome of this analysis provides input to halftone exposure programming for three-point control. Upon printing the two half tones with specified inks, paper, press, we can obtain the predetermined duotone quality. The significance of the method is that guesswork in creating duotone effects and in controlling the duotone process can be eliminated. In terms of the performance of such a method, it is a function of effort invested. In other words, it does not depend on whether you are a large printer with great financial resources, but it depends on printers who have relatively greater technical competence and manage to exercise discipline in the reproduction process.

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