EFFECTS OF CERTAIN IMAGING ERRORS IN COMPUTER-TO-PRESS SYSTEMS

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Abstract: Certain types of imaging errors that might arise from electrical or electromechanical disturbances in a computer-to-press system have been simulated and used in perceptual tests with human subjects. Displacive imaging disturbances have been categorized according to whether they occur parallel or perpendicular to raster scan lines, and whether they occur in the direction of scanning or opposite to it. The effects of such scanning errors on the quality and legibility of texts printed using Western, Middle-Eastern, and Asian character sets, and on the quality of halftones, were investigated. The detectability of the errors and their effect on legibility were found to vary somewhat according to the language of the text. In the case of halftones, it was observed that subtle changes could be produced in such a way that an observer might receive altered information without suspecting that an error had occurred.

Keywords: Defects, Digital, Printing

Introduction

The realization of systems capable of fully paginated digital output has prompted renewed interest in "Computer-to-Press" concepts. Among these concepts are some that address the requirements of variable-information printing and others that address the requirements of fixed-information printing. In both cases the final output is a product that has characteristics related to print production rather than a product in the single-copy genre associated with computer printers, digital proofers, or image setters. The difference is not manifested as much in the appearance or information content of the individual copies produced as it is in the scale of the production equipment involved. The "press" component of a "Computer-to-Press" system will have the dual functions of being the receptor of the digital stream of information and being the component that handles the flow of materials, particularly paper. The latter function introduces mechanical and electromechanical characteristics that can have a negative impact on the precision with which the former function is carried out.

Recognizing that the design tolerances that determine the precision of mechanical equipment are significantly different in a printing press than they are, for example, in an image setter, we undertook a study to determine the magnitudes of allowable error in positioning an image receptor surface relative to a digitized

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energy stream such as a laser beam. Knowing the allowable error permits the specification of machine design tolerances which ensure that the performance of the system is acceptable and that its cost is realistic. In other words, function-specific tolerancing prevents the machine from being overdesigned.

In the study we selected various examples of text and pictorial matter which were then digitized as they might be for use in a computer-to-press system. These digital images were output to hard copy in error-free form and with various errors of the type that might arise as the result of positioning errors or disturbances between the intended spatial address of an incoming bit in the data stream and the actual address where the bit is transformed into a part of the manifest image.

Using these images, we conducted a series of perception tests with human subjects to gauge the noticeability and the perceived severity of the various simulated disturbances. In this paper we describe the method used to generate the test materials, the conduct of the tests, and the test results.

Types of Imaging Disturbances

The types of disturbances we model here are shown schematically in fig. 1. The disturbances are assumed to occur either parallel or perpendicular to the direction of the scan.

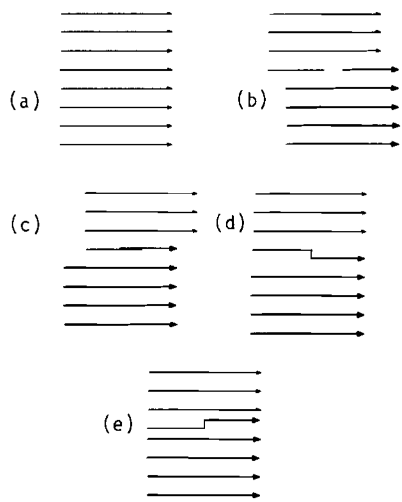


Figure 1. Types of Disturbances. (a) Normal scan, no disturbance; (b) Positive parallel disturbance; (c) Negative parallel disturbance; (d) Positive perpendicular Disturbance; (e) Negative perpendicular disturbance.

In each case, there are two allowable directions for the disturbance, positive and negative. In the parallel case, a positive disturbance is one that occurs in the same direction as the scan direction, while a negative disturbance occurs in a direction opposite to the scan direction. In the perpendicular case, a positive disturbance is taken to be one which occurs downwards (i.e., towards future scan lines), while a negative disturbance is taken to be one which occurs upwards (i.e., towards previous scan lines).

We only consider disturbances that are parallel or perpendicular to the scan line. This is because the likely geometrical arrangement of machine elements does not appear to allow disturbances to occur at arbitrary angles to the scan line. For example, consider the case of a large drum rotating and being scanned by a beam that moves parallel to the axis of the drum. In this case, the direction of rotation is perpendicular to the direction of scan. We can thus envision perpendicular disturbances occurring because of backlash in gears, or acceleration and deceleration of the drum. We can also envision parallel disturbances arising from irregularities in the scanning process. Of course, if a parallel and perpendicular disturbance occur at precisely the same instant, we might see a discontinuity at some arbitrary angle, but this is likely to be an exceptional circumstance. In any case, even if disturbances at an arbitrary angle were very likely, it would still be useful to study the parallel and perpendicular cases as a starting point to provide insight.

We make three assumptions here about disturbances. First, we assume that a disturbance occurs very fast, so that no information is transferred during the disturbance itself. Second, a disturbance represents a permanent displacement—a step rather than a pulse. In the case of a negative parallel disturbance, for example, all future scan lines start to the left of the current line. Finally, we assume that any information which has already been written before a disturbance occurs remains after the disturbance. Future information may be *overwritten* onto what is already there, but nothing is erased. Also, black may overwrite white, but white may not overwrite black. The second assumption in particular has a great influence on the appearance of images. Permanently displacive disturbances have more effect than pulse-type disturbances, in that they affect all future scan lines, not only the current one. Note that this assumption may be easily changed, and the simulation system may easily model disturbances that cause displacement for only some finite amount of time, after which the scan continues along its previous, undisturbed path.

We simulate disturbances via a computer program written in the Pascal language, and operating on Apple Macintosh computers. Image bitmaps are represented as MacPaint files, which can be created digitally or which can be scanned from hardcopy. The MacPaint format allows us to operate on an image eight by ten inches in size, with 72 pixels per inch. Higher resolutions are simulated by using an enlarged portion of an original image, and viewing it at a correspondingly larger distance.

Disturbances in Text

We concentrate on perpendicular disturbances in this paper. This is because our previous unpublished studies have indicated that these might pose a more serious problem, considering the probable geometry of a future computer-to-press system.

English Text

Fig. 2a shows a sample of English text. Fig. 2b shows this sample of text subjected to a positive perpendicular displacement of five amplitude units occurring in the second line from the top. One amplitude unit corresponds to 3.25% of the cap height in the text. Since a typical sample of newspaper text (using the *Los Angeles Times* as an example) has a cap height of roughly 2.2 mm (about 6.3 points), a disturbance of unit amplitude in our system (for this particular image sample) corresponds roughly to a disturbance of 0.072 mm (2.8 mils) in typical newspaper text. Fig. 2c shows a positive perpendicular disturbance of ten amplitude units in the same position as the disturbance of fig. 2b. The positive perpendicular disturbance has the predictable effect of introducing a white line through the text. The effect is not pleasing, but legibility does not appear to be hampered severely. Fig. 2d shows the same sample of text, subjected to a negative perpendicular disturbance of five amplitude units. The disturbance occurs on the fifth line from the top. Fig. 2e shows a negative perpendicular disturbance of 10 amplitude units, in the same place. The affected text becomes "out of focus," and eventually quite difficult to read.

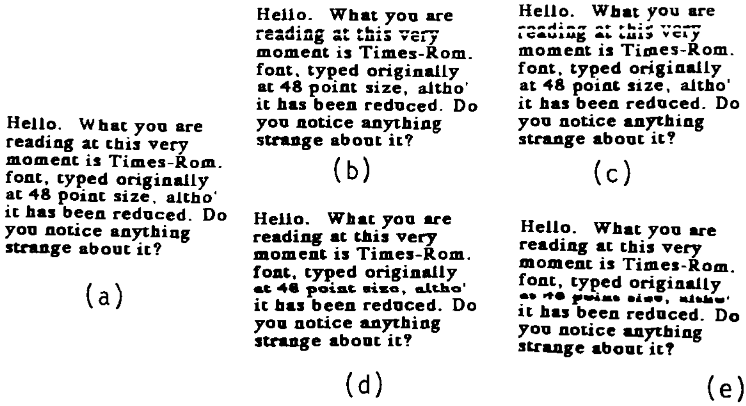


Figure 2. English Text (a) subjected to positive (b,c) and negative (d,e) perpendicular disturbances.

A series of text samples similar to those in Fig. 2 were prepared, with disturbances increasing by one amplitude unit from one sample to the next. The samples were shown to twenty human subjects, selected at random. The subjects were evenly mixed between male and female, and also represented a variety of occupations, including some secretaries, scientists, and students. The following procedure was followed with each subject: Each was shown a sample of undisturbed text, and told to examine it at his leisure. The subject was told that he would be shown other samples of the same text, and he was asked to speak up whenever he noticed anything odd or different. He was also informed that he did not have to worry about memorizing the semantic content of the text, as it would be the same every time. The subject was asked not to scrutinize the text very carefully or very long. Finally, he was told that this was not a hidden "intelligence test" of any kind, that he would not be judged on his "performance," and that the only purpose of the test was to help a printing-press manufacturer build a better product. This was told to each subject because in some initial informal tests, some of the subjects (*not* included in the sample of twenty on which our analysis is based) were actually somewhat suspicious and nervous, wanting to know "how they did," if they were "better than average," etc. We feared that these preliminary subjects might have scrutinized the samples a bit too carefully, so we prepared the twenty subjects used in the analysis by putting them at ease. Note also that none of the subjects was in any way familiar with the work we have been doing, nor did any of them have an idea of what to expect.

Thus prepared, each subject was shown a series of samples of disturbed text (either the positive or the negative series). The text was held at a distance such that it appeared to be roughly the size of typical newspaper text at normal reading distance. At each step in the series, if the subject did not notice anything, he would be shown the sample with the next highest amplitude. This would be repeated until he noticed something. If the subject could identify the disturbance correctly, the amplitude would be noted. The subject would then be shown the sample of undisturbed text, and informed of the fact. He would then be shown the other series of disturbances, and the procedure would be repeated. Half the subjects were shown the negative series first and the positive series second, and half the other way around. This was done to remove the effects of possible bias. It turned out that the two halves of the population did not differ in their behavior, and both halves are lumped together in the discussion that follows.

Fig. 3a shows a histogram depicting the distribution of subjects first able to identify the positive perpendicular disturbance. We loosely term the amplitude of first identification as the "just-noticeable difference (JND)." No one noticed the disturbance at amplitude 1, but a very large number noticed it immediately at amplitude 2. No one failed to notice the disturbance at amplitude 4. For the negative perpendicular disturbance, the results are somewhat different (fig. 3b). Only a small minority noticed it at amplitude 2, some did not notice it until amplitude 6, and there was no amplitude at which a great majority of the subjects first identified it. The mean JND is 2.4 for the negative disturbance, 3.75 for the positive. A small-sample t-test (admittedly, perhaps of questionable validity) indicates that the mean JND's differ by two amplitude units (over 6% of cap height) to 99% significance.

It is perhaps to be expected that a large number of people first noticed the positive disturbance at the same small amplitude. The positive disturbance essentially introduces an edge, and the human eye appears to be somewhat optimized for edge detection. As Rubinstein (1989) points out, neural structures in the retinas of men and mammals appear to be "designed" so that outputs to the brain occur only when edges of given orientations are present in their field. Circular areas of the fovea (the central region of the retina) respond particularly strongly when the center is lit more than the surrounding areas—as may be the case when an edge is present. Thus the initial detection of a positive perpendicular disturbance in text is possibly related to the threshold level of edge detection.

In the case of the negative perpendicular disturbance, no such consideration appears to be applicable. The negative disturbance is more subtle, and less noticeable overall. Interestingly, almost all the subjects used the expressions "fuzzy" or "out of focus" to describe the appearance of the text once they had noticed the negative disturbance.

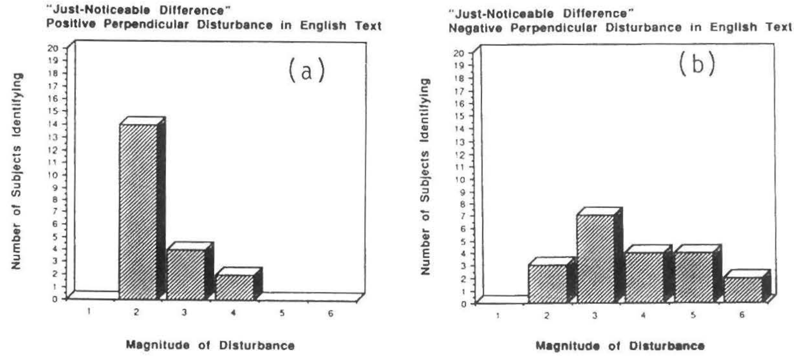


Figure 3. Detectability of (a) positive and (b) negative perpendicular disturbances in English text.

Although the negative disturbance was less readily noticeable initially, there was an indication from many of the subjects that its effect on legibility at high amplitudes was worse than that of the more-easily-noticeable positive disturbance. To explore this, we conducted another series of tests, with twenty fresh subjects to avoid bias. In this series of tests, the subjects were shown text samples in reverse order—that is, starting with the highest amplitude and progressing to lower ones. At each step, the subject was asked to read the affected line. He was also asked to provide a subjective characterization of the quality of the text, using his own words. It turned out that all the responses could easily be categorized using the following four terms: "acceptable," "somewhat annoying," "very annoying," and "almost illegible."

The results are shown in fig. 4. The positive disturbance, while it became annoying at lower amplitudes, never caused the text to become truly difficult to read. The negative disturbance, on the other hand, while it was acceptable over a greater range, did cause actual legibility problems at high amplitudes. One reason for this may be the relatively well-known fact that the tops of Latin letters seem to contain considerably more information than the bottoms (see, e.g., Rubinstein, 1989). Our positive disturbance, particularly as it occurred in the middle of the line, completely preserved the information at the tops of the letters. Only if such a disturbance were to occur at a very strategic portion in the top of the line might it present a legibility problem at high amplitude. A negative disturbance, on the other hand, given its property of overwriting, corrupts the tops of the letters at high amplitudes.

The fact that positive disturbances are more readily noticeable, but negative ones are more likely to affect legibility at high amplitudes, brings up an interesting dichotomy in design. Do we design a system so that disturbances do not ever become noticeable? Or do we allow disturbances to become noticeable, but design the system to ensure that legibility is not affected? The first approach would demand a very tight control on positive disturbances, and a somewhat looser control on negative ones; it would bias the system towards negative disturbances. The second approach would allow a looser control on both, but demand that negative disturbances never become too large: it would bias the system towards positive disturbances.

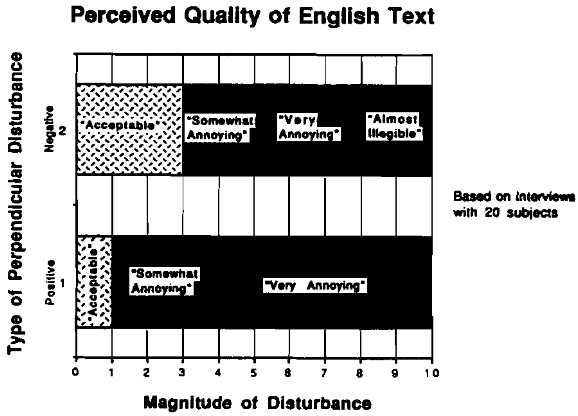


Figure 4. Perceived Quality of English text.

The positive disturbance in English text is noticeable, as we have said, at an amplitude of two, which corresponds to a real disturbance of roughly six thousandths of an inch in typical newspaper text. An error of this magnitude is within the realm of possibility in a future computer-to-press system. The negative disturbance is noticeable at an amplitude of three or four, corresponding to roughly nine to twelve thousandths of an inch.

Japanese Text

Japanese uses a system of writing very different from that of English, and in fact quite unlike any other in the world, with the possible exception of Korean. Some of the complexities of the Japanese writing system—which is *not* a simple ideographic script such as that of Chinese—are discussed in Coulmas (1989) and Sampson (1985). Because of the complexities of the Japanese writing system, and because of growing Japanese international influence and the possible importance of the Japanese market, we investigated if the imaging errors we might expect in a computer-to-press system have a different effect than they do in English.

Fig. 5a shows a sample of Japanese text, containing the usual mix of *kanji* and *kana*. *Kanji* and *kana* are fundamentally different. Certain patients with reading disorders, for example, have been found to lose the processing ability for one type of symbol but not the other. An excellent review of such phenomena is to be found in Paradis et al. (1985). At first we thought that since *kanji* and *kana* are so fundamentally different, we should really try to carry out separate tests on a text composed purely of *kanji* and one composed purely of *kana*. Closer study of the Japanese writing system proved this idea to be hopelessly naive. Although Japanese *could* conceivably be written using only *kana* (or, for that matter, using only a Latin alphabet), an attempt to do so would be extremely contrived and would produce a text which would never be encountered in practice. A text artificially produced using pure *kanji* or pure *kana* would not be a suitable sample because it would not be read by a Japanese reader using his learned and preferred reading strategies—strategies which accommodate the interaction between *kanji* and *kana*. Thus, a usual sample of text was chosen. Fig. 5b shows the text of fig. 5a subjected to a positive perpendicular disturbance of 10 amplitude units, occurring in the fifth line from the top. Fig. 5c shows the text subjected to a negative perpendicular disturbance of 10 amplitude units, occurring in the ninth line from the top. In this example, a disturbance of unit amplitude corresponds to 0.072 mm (2.8 mils) on the original image.

The perception test was administered in Tokyo by one of the authors to eleven Japanese subjects, using the procedure described in the previous section for English text. As in the case of English, some subjects were shown the positive series first, others the negative series. The results are shown in fig. 6. As in the case of English, the positive disturbance was more readily noticeable than the negative one (fig. 6a,b). It appears that the disturbance was noticed by many subjects at amplitude 1, whereas the English subjects did not notice it until amplitude 2. This may not have any meaning, since the Japanese and English tests were carried out by different experimenters, and conditions (such as the distance of the text from the observer) might have been slightly different.

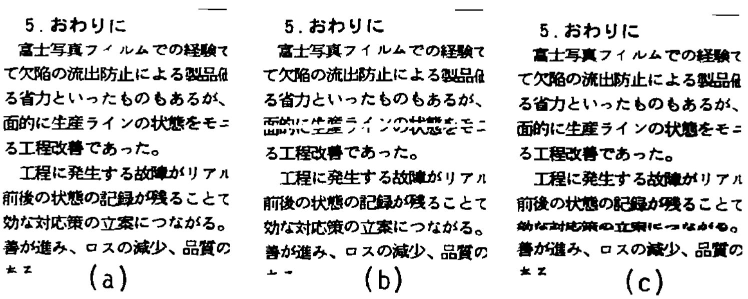


Figure 5. Japanese text (a) subjected to positive (b) and negative (c) perpendicular disturbances.

A significant number of Japanese subjects noticed the negative disturbance at amplitude 6, whereas the peak in the English distribution was at amplitude 3. This is difficult to evaluate. Unlike the positive disturbance, whose detectability probably depends largely on the detectability of a white line in black background, and not strongly on the size of the type, the detectability of a negative disturbance is certain to depend on the type size. A negative disturbance must compress and overwrite significant information in order to become detectable; therefore smaller amplitudes should be detectable sooner in smaller type. The difficulty arises in comparing the size of Japanese type to that of English type. Since it was difficult to select Japanese and English texts of the same "size," it is correspondingly difficult to interpret the different detectability levels of negative disturbances in our samples of English and Japanese text. One interesting observation is that an amplitude of 6, the amplitude at which most Japanese subjects first noticed the negative disturbance, corresponds roughly to the scale length characterizing the spacing of horizontal lines in the fine structure inside the individual *kanji*. Thus the Japanese subjects tended to notice the disturbance when it first significantly changed the kanji fine structure—by collapsing two horizontal lines into one, for example.

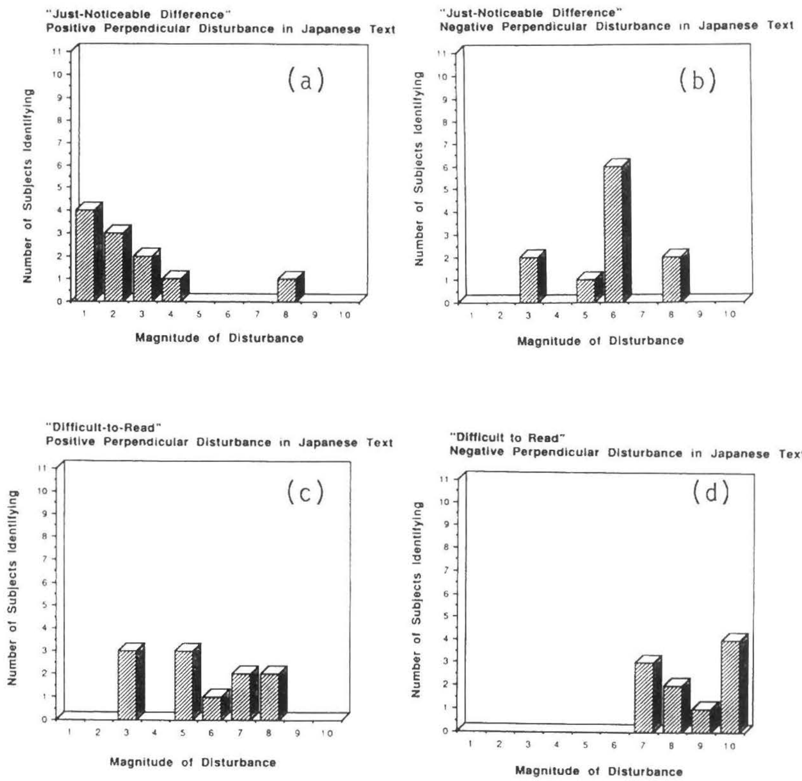
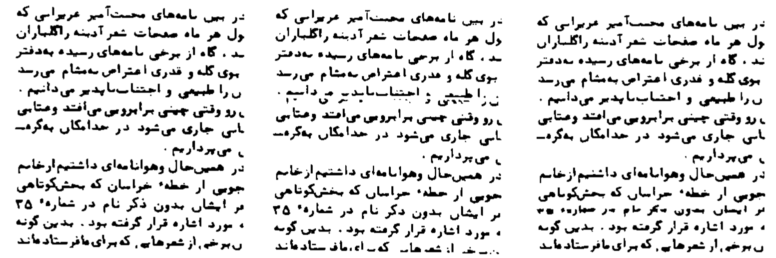


Figure 6. Perceived Quality of Japanese Text

Because of the limited time available for conduct of the Japanese tests, separate legibility tests were not carried out for Japanese subjects as they were for English-speaking ones. However, the subjects continued to be shown text samples after they noticed disturbances, and were asked to comment on the legibility. This was a somewhat imperfect test, since subjects had to comment on the legibility of text they had already read. The results, shown in fig. 6(c,d), indicate that positive disturbances become "difficult to read" sooner than negative ones. "Difficult to read" here does not correspond to "almost illegible" in the English test, but rather to "Annoying." Thus the situation in Japanese is similar to that in English. Positive disturbances are more readily noticeable, and become detrimental to quality sooner than negative disturbances. We also have indications that, as is the case in English, negative disturbances are worse for legibility at high amplitudes. Several Japanese subjects commented that at amplitudes 8-10, the text became almost illegible under the influence of the negative disturbance. One *kana* at the end of the affected line became completely unrecognizable, and was commented on by many of the subjects. This information is not embodied in fig. 6, which classifies all quality problems under the blanket term "difficult to read." Note that the separate English legibility test was carried out *after* the Japanese tests, and was motivated partly by the Japanese findings.

Farsi (Persian) Text

Farsi, or Persian, is an Indo-European language. Despite the presence of Arabic loan words and the influence of Islam, it is closer in its basic structure and indigenous vocabulary to English or French than it is to Arabic. However, it uses a cursive alphabetic script very similar to that of Arabic. Because of the different nature of the script, the potential importance of the Arabic market, which comprises over 150 million people (far more if we include all the cultures using an Arabic-style script), and the relatively ready availability of Persian subjects in Southern California, we conducted tests on Farsi text. Fig. 7a depicts the text sample we used in our tests. Those who are unfamiliar with the nature of the Farsi/Arabic writing system can consult Coulmas (1989) or Sampson (1985). In the Arabic script, a significant amount of information is carried in the diacritical marks at the bottom of a line of text. A negative perpendicular disturbance, for example, might conceivably change a ي (roughly equivalent to a "y") to a ت (roughly equivalent to a "t"), by moving up the dots on the bottom. Figs. 7b and 7c show examples of the text subjected to a positive and negative perpendicular disturbance, respectively, of 10 amplitude units. A disturbance of unit amplitude corresponds to 0.072 mm (2.8 mils) on the original image.



(a) (b) (c)

Figure 7. Farsi (Persian) text (a) subjected to positive (b) and negative (c) perpendicular disturbances.

The Farsi tests were conducted on eight subjects, all native speakers. As in the case of English and Japanese, positive perpendicular disturbances were more readily noticeable than negative ones (fig. 8a,b). Interestingly, the positive disturbance was first identified by most subjects at amplitude 3—rather high compared to English and Japanese. This may be because of the more one-dimensional nature of Farsi text compared to English and (especially) Japanese. English letters, and particularly Japanese characters, have more of a block structure than Farsi text. This means that a positive disturbance in English has a greater probability of producing a white line of more identifiable continuity in English and Japanese than it does in Farsi.

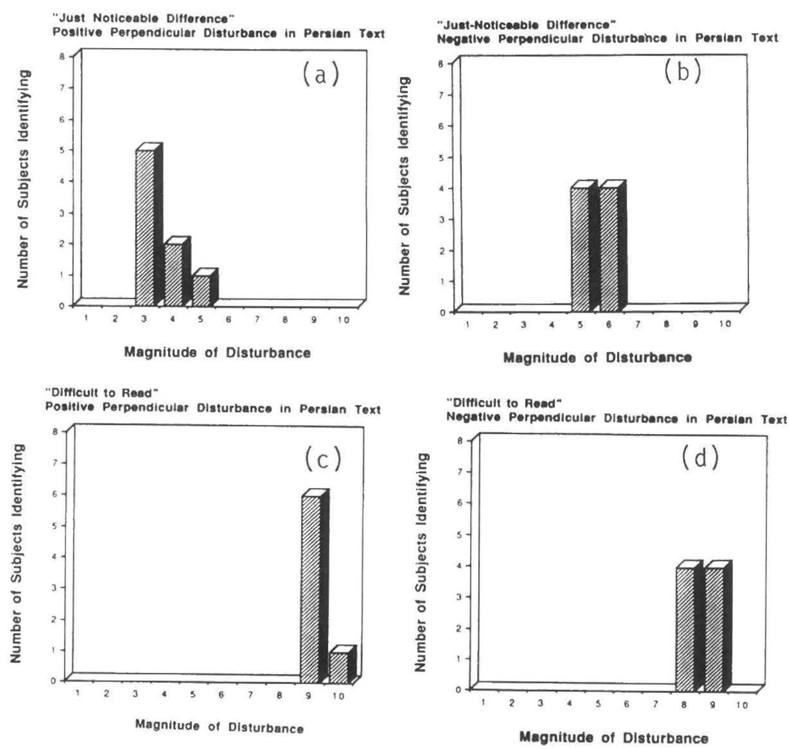


Figure 8. Perceived Quality of Farsi (Persian) Text

No separate legibility test was carried out for Farsi, but subjects were asked, as in the case of Japanese, to comment on the legibility of the text (fig. 8c,d). Although the sample is small, Farsi subjects tended not to consider the effects of either type of disturbance on legibility to be as serious as did their English and Japanese-speaking counterparts. This is again probably due to the more "one-dimensional" nature of Farsi text. Results will probably depend greatly—more so than in English or Japanese—on the exact placement of the disturbance.

Disturbances in Halftones

The effect of imaging errors in halftones may be an important consideration in design. This is because imaging errors such as the ones we have been considering have the potential not only to mar the appearance of a halftone and make it less esthetically appealing, but also to introduce artificial features. Potentially, the most pernicious effect of an imaging error may be to alter the information content of a halftone image in such a subtle way that the observer not only receives faulty information, but also does not *realize* it is faulty. We explore this possibility in the discussion below.

We have conducted simulations on a portion of a halftone which is contained on an ANPA Research Center test negative. The scene depicted is one of a pleasant, smiling woman sitting next to a cow in a rural setting. The picture contains considerable detail and tonal variation. The ANPA test negative contains three versions of the scene, at three different resolutions: 100 lines per inch, 85 lines per inch, and 65 lines per inch. We took the 65-line version, enlarged it to make a positive, and then scanned the enlarged positive into the computer. We thus did not take the approach of applying digital halftoning algorithms to a continuous-tone original, but rather chose to reproduce as faithfully as possible an original which had already been screened. Fig. 9a shows our image obtained in this way. The image clearly shows the woman's face. This is the image to which we apply various simulated errors, as shown in fig. 9b-f.

Fig. 9b shows the halftone subjected to a positive perpendicular disturbance of amplitude 2. Note that for this series of examples, a unit of amplitude corresponds to a disturbance of 0.0545 mm (2.15 mils) on the original image. The effect of a positive perpendicular disturbance is fairly obvious and does not produce any unexpected results. It introduces a blank line, which will generally be readily perceptible and recognizable as such even at low amplitudes. The effect is not subtle.

Negative perpendicular disturbances, on the other hand, have a greater potential for creating subtle distortions. Figs. 9c and 9d each show a negative perpendicular disturbance occurring near the middle of the woman's mouth. A disturbance of amplitude 5 (10.75 mils on the original) has the effect of superimposing two rows of dots, and hence creates an artificial black line through the lower portion of the woman's face (fig. 9c). Although this is not esthetically pleasing, the effect is similar in nature to that of a positive perpendicular disturbance: the defect is clearly recognizable as such, and does not alter the information conveyed by the picture. A disturbance of amplitude 10, on the other hand, is not as clearly recognizable as a defect (fig. 9d). The disturbance is somewhat out-of-phase with respect to the periodicity of the dot rows, and thus does not create a sharp dark line, only a diffuse dark zone which is more difficult to detect. Meanwhile, the error changes the information content of the image somewhat. The woman still appears to be smiling, but somehow not as broadly or as wholesomely. Thus we see indeed that negative perpendicular disturbances have the potential to alter the information content of an image, without necessarily alerting the observer that an error has taken place. Perhaps the observer will be able to see the error by looking elsewhere on the page, but even so, how is he to know that, for example, the woman should be smiling wholesomely, not grinning or smirking? Unlike the situation with text, the observer cannot mentally reverse the effects of the error.

The reader should note that the amplitudes discussed are rather large, corresponding to 10.75 and 21.5 mils on the original image. We do not expect a future computer-to-press system produced by Rockwell Graphic Systems to suffer errors of this magnitude. However, what is important here is the principle. For different images conveying different types of detailed information, smaller errors might indeed have effects similar to the ones we have been discussing.

Fig. 9e shows a negative perpendicular disturbance occurring through the woman's eyes. The disturbance (which is of amplitude 10) does not create a sharp dark line, but makes the woman's eyes seem almost closed. The woman now looks more as if she is laughing rather than smiling—her facial expression has been changed considerably.

Fig. 9f shows a negative perpendicular disturbance of amplitude 20, occurring near the bottom of the woman's nose. The woman's facial expressions are not altered but she seems almost as if she is sporting a mustache!

Of course, we have thus far chosen some relatively extreme examples. Disturbances occurring in pictures of people, and transecting their eyes or mouths, are bound to have some adverse effect. However, this only underscores a point we have made earlier. In *halftones* (as opposed to text), depending on the scene depicted and the position and amplitude of the disturbances, imaging errors may change the information conveyed in a way such that the observer may receive, without necessarily realizing it, a message subtly different from the one intended.

Figure 9. Halftone (a) subjected to positive (b) and negative (c-f) perpendicular disturbances

Conclusions and Design Implications

We have simulated the effects of possible mechanical and electromechanical disturbances in a computer-to-press system on images represented as bit-maps. Such images include pages of text and halftones. We have also conducted a number of perceptual tests on human subjects to determine the detectable levels of errors.

We have classified a series of possible imaging errors or disturbances as follows. A positive parallel disturbance occurs parallel to a scan line, in the direction of scanning. A negative parallel disturbance occurs parallel to a scan line, in a direction opposite to the direction of scanning. A positive perpendicular disturbance occurs perpendicular to a scan line, in the downward direction (towards future scan lines). A negative perpendicular disturbance occurs perpendicular to a scan line, in the upward direction (towards previous scan lines).

We have concentrated on perpendicular disturbances in this paper. This is because our previous studies have indicated that these might pose a more serious problem, considering the probable geometry of a future computer-to-press system. We have reached the following conclusions:

1). Positive perpendicular disturbances are highly detectable, in both text and halftones, by virtue of their introducing white (blank) lines in the image. In English and Japanese text, human subjects can readily detect such errors at amplitudes of roughly five thousandths of an inch. In Persian text, there is some indication that these errors may be somewhat less readily detectable because of the one-dimensional character of the text, but they are still readily detectable at amplitudes between five and ten thousandths.

2). Negative perpendicular disturbances are less detectable than positive ones in text. They have the effect of producing a subtle compression in letterforms. Unlike positive disturbances, whose detectability (although not necessarily their effect on perceived quality) is governed by the detectability of a white line in a black background and does not strongly depend on the size of the letterforms, the detectability of negative disturbances depends on the size of the text. In English text, negative perpendicular disturbances become readily detectable at approximately 9% of cap-height. For ordinary newspaper type (roughly 10 to 12 point font size), this corresponds roughly to 8-10 thousandths of an inch. In Japanese text, it appears that these disturbances become readily detectable when they reach a level roughly equal to the mean spacing of small horizontal lines in the fine structure of individual *kanji*. In Persian text they appear to become detectable when they are appropriately positioned, and large enough, to obliterate or seriously misplace diacritical marks from the bottom of the line.

3). At amplitudes lower than about 20 thousandths of an inch, positive perpendicular disturbances are perceived as a greater threat to the quality of ordinary newspaper text than are negative perpendicular disturbances.

4). Although negative perpendicular disturbances appear to be less detectable than positive ones they pose a greater threat to legibility at high amplitudes. This appears to be true for English, Japanese, and Persian text alike. For ordinary

English newspaper text with a roughly 10 or 12 point font size, negative perpendicular disturbances become a threat to legibility at amplitudes of 20 to 25 thousandths of an inch. For applications with small text, such as stock listings, negative perpendicular disturbances can pose threats to legibility at lower amplitudes (15 thousandths).

5). In halftones, perpendicular errors introduce artificial features. Positive errors introduce white lines, and negative errors may introduce dark ones as dot rows are superimposed.

6) In halftones, depending on the scene depicted and the position and amplitude of the disturbances, perpendicular imaging errors may change the information conveyed in a way such that the observer may not be able to reconstruct accurately the intended message. For example, facial expressions of people may be changed in subtle ways, without the observer even knowing that an error has occurred. Such effects appear to be limited to negative perpendicular disturbances. In our simulations on a particular halftone depicting a person's face, negative perpendicular disturbances with amplitudes of 20 thousandths of an inch were relatively serious. Other halftones might be more or less sensitive to the effects of such errors.

The effects of the above considerations on the design of computer-to-press systems depend on one's design philosophy. Consider the case of text. The fact that positive perpendicular disturbances are more readily noticeable, but negative ones are more likely to affect legibility at high amplitudes, brings up an interesting dichotomy in design. Do we design a system so that disturbances never become noticeable? Or do we allow disturbances to become noticeable, but design the system to ensure that legibility is not affected? The first approach would demand a very tight control on positive perpendicular disturbances, and a somewhat looser control on negative ones; it would bias the system towards negative disturbances. The second approach would allow a looser control on both, but demand that negative disturbances never become too large: it would bias the system towards positive disturbances. As a printing-press manufacturer, Rockwell Graphic Systems is probably more interested in preventing any disturbance from being noticeable, and would thus probably adopt the first approach.

This dichotomy cannot be resolved merely by designing everything to the tightest possible tolerances, because doing so would require compromises in other areas of system performance or would result in unnecessary cost. Our study shows that better choices can be made when the value attributes of the product to be printed are related in a quantitative way to the characteristics of the machine that does the printing.

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