36988 PDF

Fundamental and Practical Aspects of the Perception and Analysis of Real and Illusory Appearance Defects in Fabrics

Project Number: S92-9
PI(s): R.McGregor, D.Mershon, C.Pastore and H.Davis (NCSU)
Graduate Student: Mary Taylor
Post Doctoral Research Associate: Neelesh Timble

Abstract:

We have developed a much better understanding of the subtle, but crucial, perceptual factors which influence the visual appearances of defects in fabrics [1]. Based on this work, and on an earlier study of dyed fabric nonuniformity [2], a range of options for reducing or eliminating fabric streakiness has been investigated. The visual assessment of realistic printed images of computer simulated fabrics was used to evaluate the different options. Of several successful options identified only two seem generally applicable. One involves reducing the variances substantially. In the case of dyeability, for example, the %CV needs to be reduced from the ~3% currently encountered to less than 1%. A second option, programmed creeling to minimize local contrast, was found to completely eliminate the perception of streakiness with currently feasible product variabilities. It is possible that programmed creeling, a method based on removing the perceivability of streakiness without eliminating product variability, will prove to be the only practical solution for fabric streakiness.

Goal:

The goal of this project is to develop and communicate a technological understanding of fabric streakiness which is thorough enough that streakiness can be eliminated as a source of competitive advantage in the textile industry.

Objectives:

The specific objectives set for the final 18 months of this project are summarized below. This report will discuss progress made on these objectives as of August 15, 1994.

1. Quantitatively evaluate the feasible options for reducing fabric streakiness, without consideration of the "illusory" aspects.
2. Develop optimized methods for quantitatively evaluating the streakiness of fabrics.
3. Measure effects of color and spatial orientation of streaks on the perception of those streaks by humans.
4. Develop methods for comparing the results of research on model fabrics, i.e. images produced by a high quality color printer, with actual warp knit fabrics.
5. Do something, e.g. develop more realistic standards, which helps the industry with the problem of evaluating streakiness.
6. Produce definitive samples for quantitative evaluation of streakiness.
7. Based on above results, identify the best model or theory for understanding streakiness.

Background:

Streaks are visual fabric defects which are recognized as critically important problems by every fiber, fabric and garment producer who deals with fabrics of solid colors. Our approach has been to understand and evaluate the perceptual factors involved in streakiness, as well as ~~practical options for eliminating the appearance of streakiness in fabrics.~~

Streakiness arises due to variations in the contributions that individual yarns make to the appearance of a fabric. Each yarn's contribution can be represented as a "lightness" number which is based on a measurement, e.g. reflectance or K/S. If the lightness contributed by every yarn in a fabric is identical, there will be no streakiness. Variations in lightness can be caused by variations in 1)dye on fiber, 2)fiber cross section, 3)denier of yarn, 4)tightness or length of yarn in fabric, 5)spacing between wales or knit loops in fabrics, and possibly other factors. In our simulation experiments we have chosen to model fabric appearance based on variation of color depth, because ink-on-paper provides the only feasible way to create streakiness which can be precisely controlled.

The surprising fact about fabric streakiness is that quantitatively small lightness variations can produce objectionable fabric streaks. The stimulus for streaky appearance is the natural "clumping" (of higher and lower values) which occurs whenever a statistical distribution of some property is randomly sampled and examined in the sequence of sampling. A familiar example of this statistical clumping is the "grain" in a photograph. If the silver grains, which make up a photograph, were parallel lines (instead of points) the analogy would be nearly perfect. The human eye-brain system has a mechanism for creating objectionable streakiness from stimuli in which the lightness transitions are quantitatively very small. McGregor [1] first suggested that boundary, contour, or local contrast phenomena such as the Cornsweet illusion, in which a short run of warp yarns having gradually increasing lightnesses, in an otherwise uniform fabric, might generate the appearance of an abrupt step change from a uniformly darker to a uniformly lighter fabric area. This, of course, would seriously modify the visual appearance of the fabric and at the same time lead to incorrect diagnosis of the origins of the lightness variations. The importance of this particular "illusory" effect in fabric streaks has not yet been quantified, but it could be an extremely important factor. In addition the perceived lightness of a single yarn in a fabric array does not necessarily correspond with the measured luminous reflectance of that yarn.

The visibility of real streaks in fabrics is partly a function of their color and orientation. However, the effect of these factors on streak perception has been recognized only in qualitative terms, if at all. A key problem in this work is that there is no reliable, quantitative method for assigning a "streakiness" measure to a fabric. Objectionable fabric streakiness comes from intensity variations which are often too small, and too close together to be objectively measured, e.g. with a scanning reflectance spectrophotometer. Because of this a valid way to obtain a global "human perceived streakiness" parameter needs to be developed.

<u>Conclusions:</u>

- The global or overall streakiness perceived in a fabric is a mental synthesis of local contrast perceptions. These local perceptions involve the yarns within approximately ±0.5° viewing angle of any point in a fabric.
- While reduction of dye (or other structural) variability in yarns by the fiber producers will reduce streakiness, even 3.5x reductions in %CV below current commercial norms are expected to 1) leave marginally detectable streakiness in warpknit fabrics and 2) be difficult to achieve.
- Of the options available only program creeling, to reduce local contrast fluctuations below the limit of perception, was realistically able to eliminate streakiness. Program

creeling requires advance knowledge of the lightness of each end of yarn.

- o Program creeling, which has been demonstrated effective in polyester circular knits, may be ineffective with some current nylon yarns because of "along the end" variability on the scale of 100m and larger.
- o The human modulation transfer function, which has been determined for sinusoidal and other simple contrast variations, applies reasonably to the random streakiness in warp knit fabrics. Further experiments to refine this analysis are planned.
- o Illusory streaks are potentially important, particularly if program creeling is practiced. A relatively large scale experiment to understand illusory streaks will be complete by September.
- o The well known "dye it yellow-to-remove-streakiness" phenomenon is more related to perception factors than to the diffusion properties of yellow vs. other dyes.

Results:

1. Options for Eliminating Streakiness

Experimental Method

The results described in this section were all achieved on model fabrics produced with our Iris 4020 printer. This printer operates on 8 bit greyscale values for each of four inks: cyan, magenta, yellow and black. A monochrome fabric model was generated by randomly sampling a normal distribution of numbers with a mean of 128 and a variance set as required. These numbers were used to draw parallel "lines" which represented yarns in a fabric. Using a software package called "Photoshop", the resulting image was interpreted and put into printable form. A greyscale value of 128 (50% lightness) represents about 18% reflectance, as is common in photographic printing. Photoshop could also convert greyscale images into monochrome images of any color as represented by a constant mixture of the four inks. The transfer function of the printer near the 20% reflectance point was adjusted as needed to provide lower effective variances than were convenient with 8 bit integer data. The printer transfer function was calibrated by printing 1 inch square patches corresponding to 6 greyscale values between 116 and 146, and measuring these with a MacBeth 1500 color analyzer. A method was also developed to produce model fabric images with 1/4 bit greyscale resolution, but these were hardly distinguishable from the 1 bit resolution images, which were used for most of the work. The results reported below were all derived from A-B comparisons in which the effects reported were easily visible. This approach was necessary because a quantitative assessment method has not been developed yet.

Signal to Noise Issues

By definition a streak is a lightness perturbation which persists along a line for a significant distance. If the "illusory" aspect of streakiness is ignored, the perception of a streak becomes a signal-to-noise issue. The exact nature of the signal is not known. However, it can only be that "signal" represents a "clump" of (e.g.) lighter yarns between two clumps of darker yarns. Since the clumping mentioned here is the result of randomly sampling a set of yarns having a certain probability distribution of lightness, the concept of "noise" can only reflect the variability of the yarns along their ends. One option for eliminating streakiness, therefore, might be to increase the along-end variability of lightness, and experiments were done to test this hypothesis. When the %CV of (normally distributed) along-end noise is about 5x larger than the end-to-end %CV, the perception of streakiness is replaced by a "hashiness", which may be acceptable. Other types of along-end noise, e.g. slubs and random phase sinusoidal noise, were less effective than normally distributed noise. It is possible that this is a feasible way to reduce streakiness. However, at present no method is known for inserting normally distributed noise along a continuous filament threadline.

Reducing Product Variance

Typical nylon yarn products have a variability of lightness after critical commercial dyeing of about 2.5%CV. The fabric modeling method we developed permitted modeling randomly creeled fabrics with arbitrarily low %CV of lightness. We found that reducing the %CV of the "yarns", which can be done by 1) the fiber producers making more uniform yarns, 2) using leveling dyes or 3)co-mingling multiple ends of yarn into the same yarn, will reduce streakiness. After calibrating the transfer function of the printer, we found that a 3.5x reduction in %CV gave a much reduced, but still apparent perception of streakiness. While making the yarns more uniform will help, this result suggests that to truly eliminate streakiness in randomly creeled warp knits, will require %CV's well below 0.7. It is possible that such low variabilities can be reached with appropriate dyeing procedures.

Interlocking Stitches

Fabric producers have the option of designing fabrics with interlocking stitches. This means that no individual yarn completely occupies any line (or course) in the fabric. A Jersey fabric, e.g., has almost no interlocking. Because the method for simulating fabrics was under perfect control, a fabric could be generated without interlocking, and the comparison fabric could be generated using exactly the same yarns in the same sequence. The interlocking method studied was to have line "n" in the fabric consist of 50% yarn "n", 25% yarn "n+1" and 25% yarn "n-1". This kind of interlocking reduced the appearance of streakiness to approximately the same extent as reducing the %CV of the yarns by a factor of $\sqrt{2}$. Note that while stitch interlocking is superficially similar to along-end noise, it is formally different, and more effective, because the noise in this case is derived from populations having different means from the sample being modified.

Table I. Effect of Color on Streak Perception

Appearance	K/S slope	L* slope
Cyan 2 (Worst)	.021	.0115
Cyan 1(Intermediate)	.012	.012
Yellow (Best)	.015	.005

Dyeing to High Chroma

For many years, streakiness has been known to be less of a problem in yellow than in blue fabrics. The reason has been uncertain: perception or diffusion/physics? Table I shows results of fabric simulation experiments. The three simulated fabrics shown were made from the same pattern of greyscale values. Streaky appearance was clearly visible in the cyan fabrics but could not be detected in the yellow fabrics. Calibration of the transfer function showed that the yellow fabric actually had a larger relative dye (K/S) variability, than a cyan fabric which was easily seen to be more streaky. Using L* to normalize, instead of K/S, ranked the yellow item correctly, but did not discriminate the blue ones. This clearly shows that the known freedom of yellow fabrics from streaks is probably not related to the diffusion properties of the dye. The main reasons for the observed results can be deduced from the CMC (l:c) color difference equation, and the Munsell Color Charts. These effects are more perceptual than physical.

Program Creeling

As was explained in the section on signal/noise above, streaky appearance in fabrics depends, at least in the non-illusion case, on local clumping of lighter and darker yarns together as a result of randomly sampling a statistical distribution. An experiment was carried out in which two model fabrics were made from the same "yarns". In one fabric the yarns were randomly arranged. In the second fabric the yarns were arranged so as to minimize the local contrast which would result from lighter and darker yarns clumping together. The results of this experiment were shown in the June 1994 NTC Quarterly Report. It was easy to see that there was no perceptible streaking in the sample which had been "program creeled" to minimize local fluctuations, whereas the random sample had substantial streaking. This kind of program creeling seems capable of making streakiness completely imperceptible, even for a reasonably nonuniform set of yarns. Furthermore it is the only option identified which can produce imperceptible streaking with the variability expected in commercial yarns.

2. Testing Human Perception of Illusory Streaks

The existence of perceptual phenomena, such as the Cornsweet or Craik-O'Brien illusions, means that the appearance of streakiness in fabrics could arise due to imperceptible gradual transitions from light to dark or dark to light. It is important to understand whether these illusory streaks are functional in the stripiness of fabrics, because the eye-brain has the ability to amplify apparent stripiness through this mechanism. Current work has been aimed at developing valid methodologies for studying human responses to streaks and to determine if illusory streaks obey the same kind of psychophysical rules as do "real" streaks as described in Section 1.

The visibility of real stripes/streaks due to dye differences is partially a function of their color and orientation. For example, a given level of physical streakiness will be less apparent in a fabric dyed yellow than in cyan or almost any other color, as was explained in Section 1 above. Many non-illusory streak defects are more easily seen when a fabric is in a particular orientation. In the experimental program to be described now, we are looking at effects of color and orientation on the discriminability of illusory stripes created by the gradual transitions in luminance described above.

Images have been made in which there are four panes, each of which contains a central section that appears either darker or lighter than the adjacent areas (i.e. there is a centrally located streak). These central streaks were produced with different strengths by manipulation of the Cornsweet illusion. In most of the images, exactly one of the panes will have a central streak which is different from(i.e. either slightly lighter or darker) the others. Judges will be asked to identify the panel in each image which contains the dissimilar streak.

Several factors will be systematically varied during the experiment. These include the color (grey, cyan or yellow) and the orientation of the image (horizontal, vertical or 45° oblique both right and left). Half of the centrally located streaks will involve a positive difference, i.e. streaks lighter, and half will involve a negative difference. For each case the odd streak will be slightly stronger than the others. After judging randomly selected practice samples, the actual experimental images will be presented to the judges in quasi-random sequence, separated into blocks of 24 images having the same color. This design helps prevent uncontrolled shifts in color adaptation of the eyes between images, such as might occur if color were also randomized.

There are a number of controls to insure the validity of these experiments. All presentations will take place in an illumination-controlled viewing box which has been designed and constructed over the past few months. Images will be shown against a neutral gray background with approximately the same reflectance. The images will be shown at eye-level, in the fronto-parallel plane (i.e., they will be observed by looking straight ahead at stimuli which are perpendicular to the line of sight). The different orientations therefore represent differences of rotation within the fronto-parallel plane.

The following primary results (based upon both a theoretical understanding of vision and practical experiences with "real" stripes, are expected: 1)correct detection of the odd stripe should be better when the panes are oriented either vertically or horizontally, than when they are viewed at one of the oblique orientations (i.e., performance at 0° or 90° will be superior to performance at +45° or -45°); 2)detection of the odd stripe will be very poor for the yellow images, even though the physical differences to be presented will be intentionally larger than those for the cyan images. In addition to an interest in overall performance differences, we will be examining whether the extent of performance change with orientation is comparable across the gray, cyan and yellow stimuli. The results of this set of experiments will aid our understanding of whether the perception of "real" and illusory stripes is mediated by similar visual mechanisms. They should help in predicting the most likely situations in which illusory stripes might appear.

3. Fabric/Streak Evaluation Methodology

Assigning a quantitative value which represents the perception of streakiness in a fabric is a difficult and imprecise operation. Normally a team of 4 (or more) skilled textile marketing personnel will compare fabrics with AATCC Standards on a 1-10 scale. These current standards do not look much like real fabrics, and often different graders get different results.

A key part of this project hinges on developing valid methodologies for evaluating the severity of streakiness in a fabric. It seems that the only way to judge the severity of streakiness is to bracket an unknown between two knowns. Even so, with current "Standards" which do not look much like fabrics, there is considerable variability among different people doing the evaluation. We think the more realistic model fabrics we produce will make much improved standards for fabric rating.

Recently we performed a test in which we asked a random group of people to rank a set of model fabrics having similar streakiness. Three standards had known differences. The unknown sample was being tested for streakiness, and the result obtained, which will be discussed under Table II, showed that almost everyone ranked the fabrics the same. The "known" fabrics were also rated in the correct order based on their design. Note that the model fabric designated "unknown" was rated very definitely between fabrics 1 and 2, which had well controlled streakiness.

The suitability of our simulated fabrics for streak standards has now been discussed with many people in the textile industry. It is generally agreed that standards made by our method would be a substantial improvement, and we expect that eventually the standards will be based on our (or equivalent) model fabrics. At present, however, there is no one who thinks it

Table II. Consistency of Streakiness Grading

Designed Ranking>	1	2	Unknown	3
Observed Ranking↓				
(Worst) 1	100%	0%	0%	0%
2	0%	7%	93%	0%
3	0%	80%	7%	13%
(Best) 4	0%	13%	0%	87%

is more important to improve the standards than to eliminate streakiness. Consequently we expect no further action on improving industry streak standards for the balance of this project.

4. Confirming Model Experiments with Real Fabrics

We have tried again to characterize a set of nylon warp knit yarns produced by an industrial partner so that real fabrics could be designed and evaluated for streakiness in a manner analogous to the model fabrics discussed here. In doing such an experiment, it is important to be certain that the part of the yarn which is characterized will be the same as the part that is used in test fabrics later. To confirm this, we sampled each of 240 packages of yarn (Samples A), stripped each package and sampled each one again (Samples B). Characterizing the yarns in this case means measuring the amount of dye absorbed by each yarn in an industry standard competitive dyeing procedure. For the desired experiment to be possible, Samples A must correlate with Samples B within the accuracy of experimental measurements. We performed extensive analysis and statistical studies on the results. The final conclusion is that the test yarns vary enough along their length (on the 100m or longer scale) that the desired experiment cannot be done.

This is the second set of nylon yarns in which this problem occurred. No similar problem occurred in previous tests with small lots of textured PET yarns, and we originally intended to back up the nylon test with a similar one on PET. Unfortunately the PET tests probably cannot be completed before the end of this project.

5. Understanding the Fundamentals of Streakiness

Understanding the fundamentals of streakiness, at the low levels which cause problems in textiles is complicated. Actually there are two factors to be considered. One involves what might be termed "real" streaks or stimuli, as discussed in Section 1; the other involves illusory streaks, i.e. the result of the eye-brain system interpreting the stimuli.

Perception of a real streak involves the mapping of the object, i.e. the actual pattern of lightnesses, into an image, i.e. the perceived image. The mapping function is called the modulation transfer function (MTF) in one formalism which is used in optical system design.

MTF is a blurring function; i.e. it causes the image to have less detail than the object. In past as well as current modeling work, we have observed that an MTF equivalent to a 5 point moving average approximates an observer looking at a 40 epi fabric at a distance of 1 m. In this case the presence of a barely perceivable streak is signaled by the existence of contrast greater than 1.5% in a band which subtends a 0.3-1° angle at the observer. This approximation agrees with some large scale industrial experience as well as with the results in Reference 2. Furthermore this result is consistent with recent work (See McGregor et.al. under Publications) which suggests, based on rectangular wave contrast experiments, that the human MTF has a broad maximum for angles around and greater than 0.1° per cycle of contrast. Although the work all hangs together, we are still improving our understanding of the MTF, because this function must be known precisely if program creeling is to be practiced competently.

Based on this understanding, it is clear that streakiness in a fabric is locally determined, i.e. within a viewing angle of about 1°. Consequently the same set of yarns which produce a light streak in one part of a fabric might produce a dark streak in another part of the same fabric. In fact this "local" characteristic of streakiness is what makes it possible to eliminate streakiness with program creeling.

An additional factor pointed up in this work is the ability of the eye-brain system to average along and detect a streak in an extremely noisy background. Even when the along-streak variation is 5x the standard deviation of the yarn population, it is possible, albeit barely, for the eye to discern streakiness. Only when the along-streak variation is 10x that of the population do the streaks become completely undetectable. This represents a remarkable averaging ability of the eye. In the event of periodic fabrics such as circular knits, the eye would also have the ability to use the repeating nature of the barre' to average out noise. Some evidence for this has also been discovered. We find that the CV of K/S required to essentially eliminate streakiness is about the same for warp knit as for circular knit fabrics. Should the periodic nature of the circular knits not be involved in perception, the statistical situation would imply that significantly more-variable yarns would be satisfactory in 36-80 feed circular knits than in 3000 feed warp knits.

At this point it should be apparent that any program creeling algorithm which eliminates streakiness due to random "clumping", must organize that clumping into designed patterns in which lightnesses change gradually. Herein lies a danger that illusory streaks will be produced as "real" streaks are eliminated. Therefore it is imperative that illusory streaks in fabrics be thoroughly understood.

A more advanced mapping formalism is a "neural network" model which attempts to account for processes which happen inside the eye-brain system. This approach will probably be needed to understand the illusory component in streak perception. We are also working to determine how to put the knowledge gained in this program into the neural network formalism.

Program

For the balance of this project we will:

- o Complete the human response experiments on illusory streaks described in Section 2.
- o Devise computational algorithms for program creeling which depend on the current best MTF, and examine the results of these for patterns likely to cause illusory streaks.

- o Continue to work on the MTF and understand how to apply the neural network formalism to fabrics.
- o Complete a publishable paper on the work described in this report.

Publications/Presentations:

A paper, "Perception, Detection and Diagnosis of Appearance Defects in Fabrics", has been accepted for publication in the Textile Research Journal. There have been three formal presentations of research results in the area of fabric appearance at two Ciba-Geigy sites (Greensboro NC and Basel Switzerland) and at the University of Mulhouse (France). In addition an invited lecture and a poster were presented at the May 1994 Fiber Society Meeting. The work dealt with streakiness in circular knit fabrics and with factors in fiber microstructure which lead to dye streaks. We have had two industrial groups come to NCSU in the past two months to discuss the work of this project, and a third has requested that we find a way to bring the information to their research facilities.

References

1. McGregor, R. Text. Chem. Colorist, **1984**, 16, 21

2. Kearns, E.R., Davis, H.A. and J. Coryell, *Knitting Times* **1978** 47(42) 16