Product characterization and problem solving using an image analyzer

J. ROBERT WAGNER

ABSTRACT

This paper highlights the versatility of image analysis as a tool for characterizing products, solving problems, and investigating materials and items that affect manufacturing processes. Examples presented include yarn and fabric analysis (dyeing and soiling of fabrics, sewn-seam puckering, pilling, fabric squareness), evaluation of filters for aerospace applications, assessment of tennis ball quality, and other items. The discussion emphasizes the importance of the image analysis hardware and software; the proper choice and use of lighting, optics, and statistical methods; and the skill and knowledge of the operator.

Application:

Demonstrates the versatility and utility of image analysis as an analytical tool.

IMAGING SYSTEMS HAVE GREATLY ADvanced our ability to characterize and analyze materials, assess quality, and solve problems. An image analysis system consists of a charge-coupled device (CCD), camera, optics, lighting, computer with a second monitor, imaging software, and sometimes other auxiliary fixtures or equipment. For some applications, a flat-bed scanner, slide scanner, VCR, or digital camera might be used to capture the image being investigated. Sometimes a spreadsheet is used to automatically record the data as it is collected. Statistical software is also useful in formulating equations for prediction or assessment purposes.

The importance of selecting an optical system that can achieve the desired magnification in the region of interest without image distortion or blurring cannot be overstressed. Lighting is especially important. One must decide whether the specimen being examined is to be backlighted or illuminated by incident light, and the angle of lighting is a very important consideration in obtaining the desired results. The type of lighting, whether white light, laser light, filtered light of a specific hue, plane or circular polarized, and the intensity of the light are all important considerations.

It has previously been reported that an image analyzer can be used to improve the accuracy of air-permeability measurement *(1)*, evaluate the uniformity of nonwovens *(2)*, determine the linting of nonwovens *(3)*, establish fiber orientation, and relate bonding pattern to tensile strength. There are countless other end use applications. This report presents a wide range of applications to demonstrate the versatility of the image analyzer.

YARN ANALYSIS

Figure 1 is a photograph of a streaky woven fabric. Image analysis revealed that there was a 30.6% variation of yarn diameter from the desired target. The fault was traced to faulty equipment that stretches broke filament into staple fibers. Mass (capacitance) yarn testing is the conventional method for determining yarn uniformity. Optical yarn classification is an alternative method that can determine the extent of neps, thick or thin places, short and long faults, and periodic or random unevenness *(4)*. Image analysis also obviates the need to ravel the yarn from the fabric, since it can be examined while still in the fabric. Another interesting use is to characterize hairiness and the extent and quality of textured yarns.

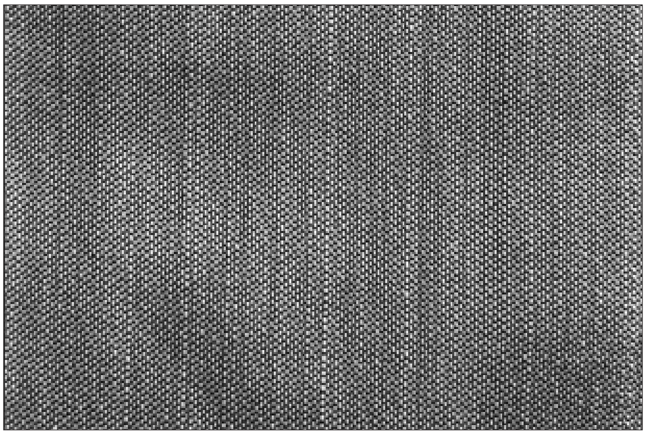
Recently, I had to analyze a complex endless woven belt that was reinforced with a plastic core, i.e., a central plastic membrane. It was not possible to extract one of the systems of yarns to get a weight determination that would establish the yarn number used. Even if the yarns could have been raveled out, the weight would have been too low (the result of pulling fibers out of the yarn when it was removed from the plastic) or too high (the result of plastic adhering to the yarn). To circumvent these problems, the image analyzer was used to determine the yarn cross-sectional area. From this, the circular diameter—and therefore the count yarn number—could easily be determined using Eq. 1 *(5)*.

$$\text{Area} = \Pi(D/2)^2 \qquad (1)$$

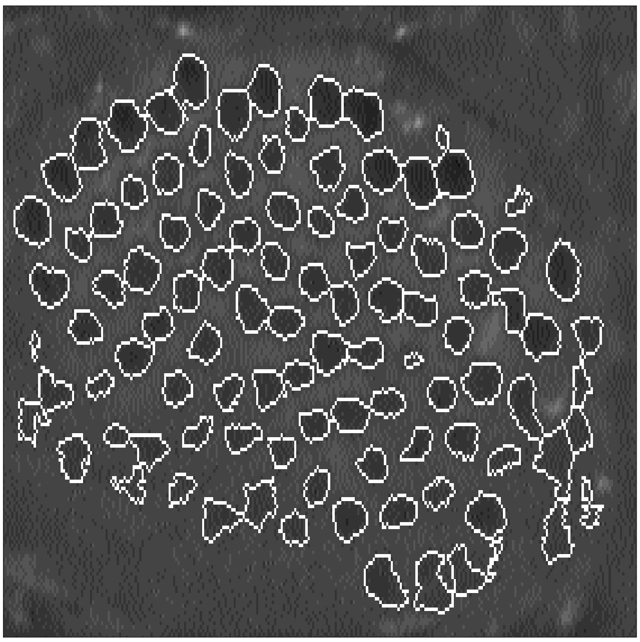
where D is the yarn diameter, which can be solved for because the area was measured with the image analyzer. Once D has been calculated, the cotton count, cc, can be obtained using Eq. 2 *(5)*.

$$D = \frac{1}{\text{CCF (cc)}^{1/2}} \qquad (2)$$

where CCF (compact cover factor) is known for a given generic fiber type. The CCF accounts for the generic fiber specific gravity and yarn air space for a No. 1 cotton count yarn. This can either be looked up in a table or calculated. Since the yarn was a continuous filament yarn, the denier can be determined by Eq. 3.



1. Streaky woven fabric



2. Cross-section of yarn embedded in rubber with filaments outlined

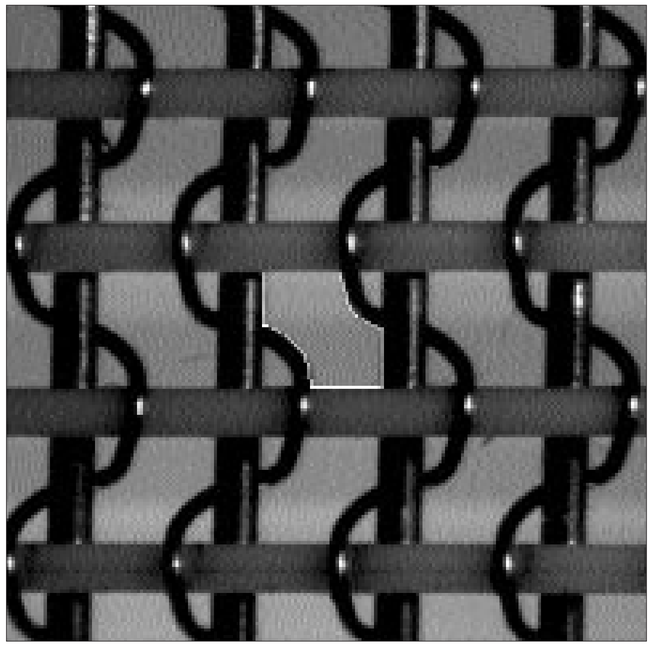
$$\text{Yarn denier} = \frac{4{,}464{,}492}{840 \text{ cc}} \quad (3)$$

The total number of fibers in the cross section of the filament yarn can be determined using an image analyzer, as shown in **Fig. 2**. By comparing the number of filaments in the yarn cross section and knowing the approximate denier of the yarn, the actual denier and often the name of the fiber supplier can be determined from a table of deniers, filaments, and generic fiber types that is cross referenced to the various fiber manufacturers.

Area, in.^{2}	0.003713
Perimeter, in.	0.25989
Major axis length, in.	0.09741
Breadth, in.	0.06567

* Opening is illustrated in Fig. 3

*I. Measurement of opening in leno-woven aircraft filter**



3. Aerospace filter with large pore outlined for data extraction by image analysis

DYEING AND SOILING

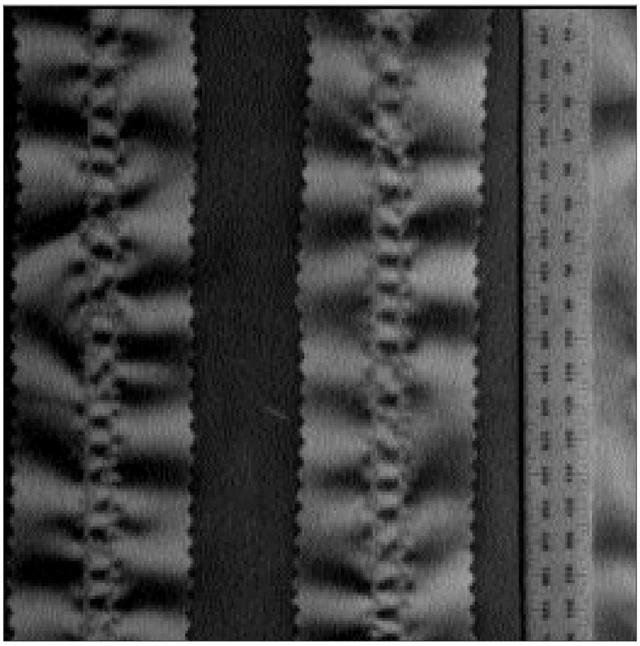
Image analyzers can be used to assess the levelness of dyeing and the fastness of dyes to light, washing, dry cleaning, and gas fading. In addition, it can determine the degree of soiling in apparel, carpeting, and upholstery before and after cleaning, or it can measure the effect of soil-resistant finishes that can be applied to fabrics.

AEROSPACE

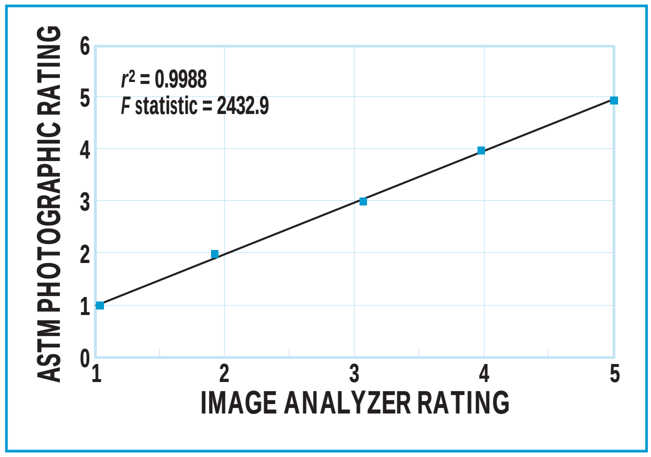
Figure 3 illustrates a leno-woven, high-tech, specialty filter. When electrified, the filter can determine (in real time) the size, rate, and total amount of metallic chips and particles that slough off oil-wetted parts of aircraft engines, helicopter gearboxes, and power generating systems. Such detection provides advance warning of metal fatigue and spalling and, depending on the measurements obtained, can dictate the need for maintenance or alert the pilot to shut down the engine or cease the flight to avoid catastrophic failure. In this particular application, the image analyzer is used to determine the size of the irregularly shaped filter pore openings. The area, major axis length, breadth, and perimeter of the filter opening—indicative of the size of the metallic particles—are easily obtained. **Table I** shows these data for the filter opening outlined in Fig. 3.

SEWN-SEAM PUCKERING

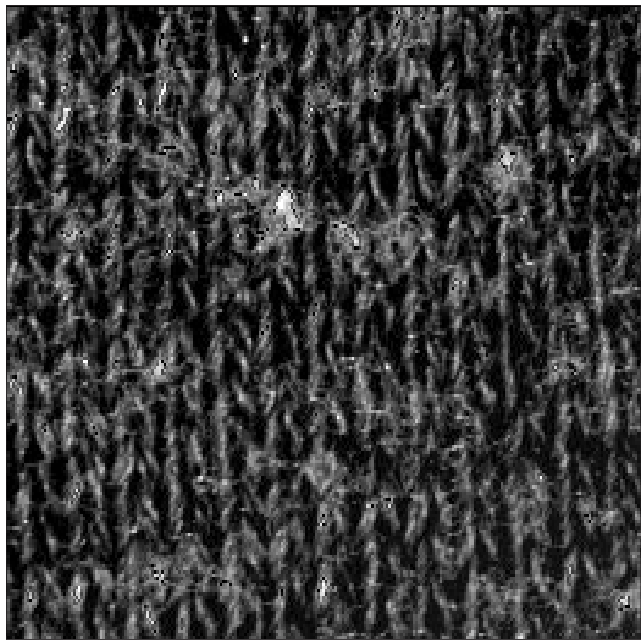
Seam puckering is a problem associated with the inherent properties of the sewing yarn (e.g., shrinkage), yarn tension while sewing, sewing machine mechanics, and fabric shrinkage. To rank seam puckering, AATCC has two sets of photographic standards with five levels of



4. AATCC photographic ranking standard for poorest levelness of double-needle seam



5. Relationship between image-analyzer rating and AATCC double-needle seam ranking standard



6. Fabric sample (130.5 mm²) with pilling outlined for data extraction

seam puckering *(6)*. One set is for single-needle seams, and the other is for double-needle seams. **Figure 4** illustrates a ranking of "1," or the worst score for a double-needle seam.

When using visual standards, the ranking obtained largely depends on the evaluator's ability to subjectively rate the sewn article with the visual photographic standards. This can lead to inaccuracies in the results reported. To circumvent this difficulty, an image analyzer can be used to make the ranking in a consistent manner.

To establish an image analyzer ranking system that correlates with the AATCC standard, one must first standardize the area from which the measurements are to be made. At a particular magnification, this is known as the region of interest (ROI). Using a constant ROI, the two sets of seam standards were captured. The next step was to establish the totals, means, and standard deviations for the light and dark areas. Separate regressions were performed for light areas and dark areas as related to the AATCC seam-puckering ranking of 1 to 5. The regression coefficients for the light values were used to establish half of the ranking, and the regression coefficients for the dark values were used to find the other half of the ranking. The ranking results were then averaged to obtain the final estimated ranking. A simple linear regression equation was then used for the double-needle seam:

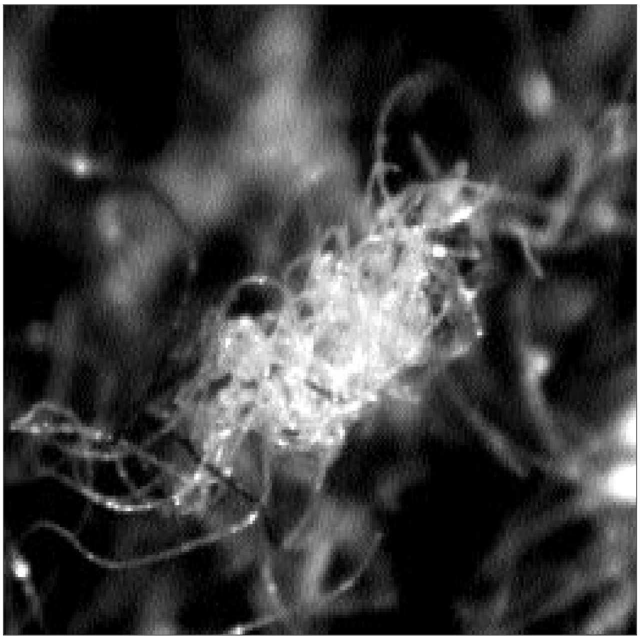
$$Y = -0.0030584 + 1.00102x \qquad (4)$$

where x is the ranking determined by the image analyzer and Y is the AATCC photographic ranking. As seen in **Fig. 5**—with an r^2 value of 0.9988 and an F statistic of 2432.9—it is apparent that the image analyzer gives exactly the same levelness ranking for the double-needle seam as the AATCC subjective photographic ranking.

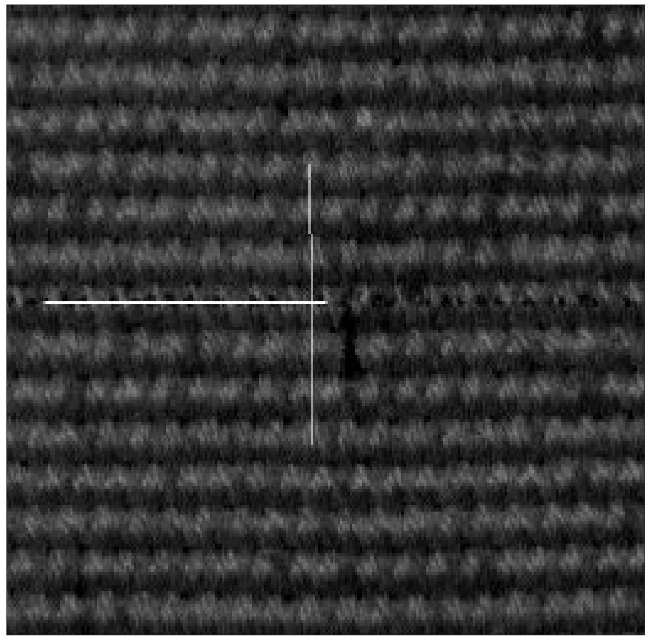
Total pills	89
Pill area	
Mean, mm²	0.0163
Std. dev., mm²	0.0238
COV, %	146.01
Pill perimeter	
Mean, mm	0.6122
Std. dev., mm	0.3628
COV, %	59.26

II. Pilling measurements

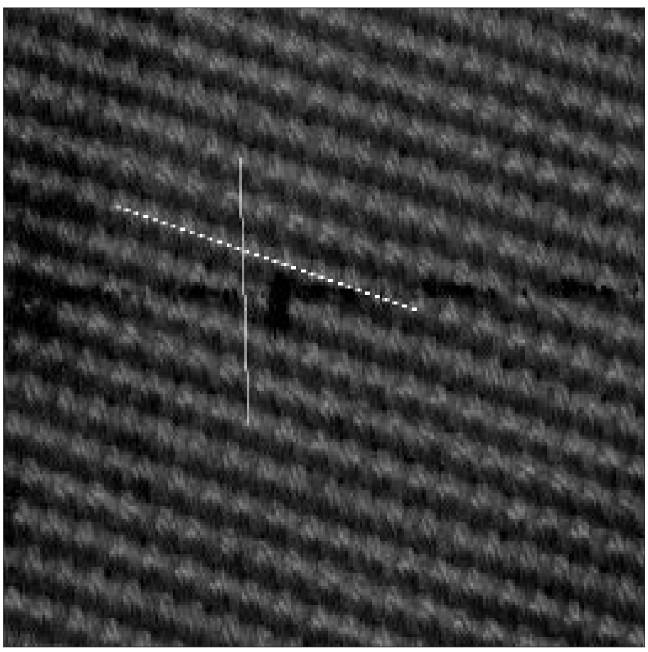
For single-seam puckering, the same form of equation gave an r^2 value of 0.9422 and an F statistic of 48.88. With the



7. Fabric sample (2.12 mm²) showing that pilling consisted predominantly of white polyester fibers



8. Square fabric; overlay of white pixel lines indicates angles of warp and filling yarns



9. Nonsquare fabric; overlay of white pixel lines indicates angles of warp and filling yarns

almost perfect fit for the double-needle seam and slightly poorer fit for the single-needle equation, this may suggest that the single-needle ranking standard has not been accurately established by AATCC and perhaps should be revised.

Once the equations for ranking sewn-seam puckering or levelness have been established, the image analyzer can be used, thus eliminating evaluator subjectivity as a source of ranking errors.

PILLING

Pilling occurs when fibers on a fabric surface work free and form balls. Natural fibers such as cotton, wool, and linen tend to wear away and, therefore, are less prone to pilling. Synthetic fibers such as nylon and polyester have superior abrasion resistance. Because they do not wear away, they tend to form unsightly pills. Pills formed with multicolored lint or a mixture of fibers with different colors are more noticeable because they usually do not match the background color of the garment.

Figure 6 illustrates a fabric area of 130.5 mm². The image analyzer was used to automatically designate the pilled areas and then categorize the number and size of the pills. The results are shown in **Table II**.

To study the pilling further, the image analyzer was used to substantially magnify the surface to an area of only 2.12 mm², as shown in **Fig. 7**. It was determined that the fabric was composed of a blend of polyester and cotton. When dyed, the cotton dyed black, but the polyester remained white. It is apparent that the pill is composed primarily of the white, abrasion resistant, polyester fiber. The black cotton fibers, being less resistant to abrasion, are few in number, so the pill appears white against a dark gray–black background in the actual garment. Had the polyester been dyed too, the pills would have been less apparent.

Many nonwovens used for thermal lining of winter coats are needle punched and have a tendency to pill. The image analyzer is a very useful tool to establish the type and extent of pilling. Using this information, the fabrics can be ranked for their pilling index. Or a manufacturer might use image analysis results to alter process variables and reduce the pilling tendency.

FABRIC SQUARENESS

When woven fabrics are manufactured, one of the goals is to produce fabrics that are square, i.e., with the filling yarns perpendicular to the warp yarns. Two examples where fabric squareness can affect end use performance characteristics will be discussed.

Nonsquare fabrics can cause basis-weight variations in papermaking and on nonwoven melt-blown, spunbonded, and air-laying lines. If a press fabric or dryer fabric is not square, it can cause narrowing of the fabric, producing wet and dry streaks in the product being manufactured.

Wet and dry streaks in paper or nonwoven webs can cause product inconsistencies and reduce profits. The differing characteristics of wet and dry streaks in a product can cause puckering, differences in surface characteristics, and other problems. When wet streaks occur, the product is usually then overdried to remove the excess moisture in certain areas, and profits are reduced if the product is sold on a cost-per-ton basis. Uniform sheet drying allows a company to maximize profits as well as product quality.

Paper machine clothing—forming fabrics, press fabrics, and dryer fabrics—is commonly manufactured with cross-machine stripes that are either woven in the fabric or applied using pigments in a resin or binder. These colorful stripes serve two purposes. First they serve as a trademark for the manufacturer. Secondly, and of much greater importance, the stripes serve as an indicator to assure that the fabrics are running properly on the paper machine or nonwoven production line. If the stripes have a leading/trailing edge or a leading/-trailing bow, the fabrics are easily straightened out using a bowed roll, bowed bar, crowned roll, or a concave roll. On the other hand, an "S" shaped distortion is much more difficult to remove or straighten out. Fabrics operating as belts that are not so marked are especially problematic, since it is difficult to see if they are running square.

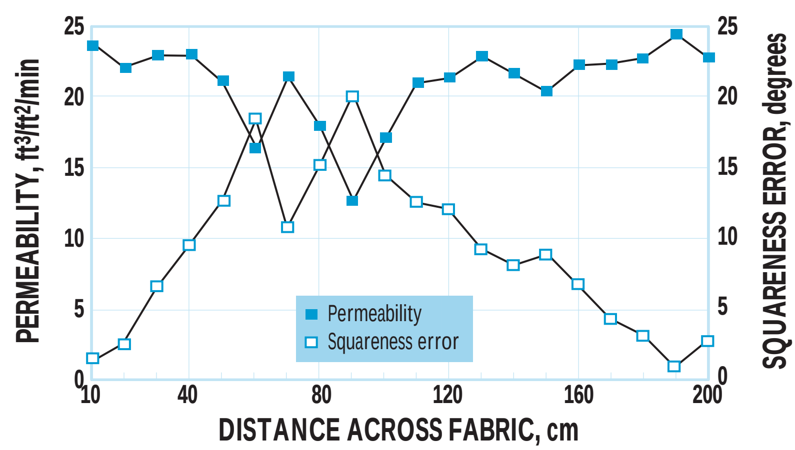
A dryer fabric that exhibited various operating difficulties in the dryer section of a paper machine was marked every 10 cm across the fabric and checked for warp and filling squareness (i.e., the amount that the yarns deviated from the perpendicular or 90°). Fabric permeability was measured in the exact same areas where the image analysis squareness of the fabric was measured. **Figure 8** shows a relatively square fabric, while **Fig. 9** illustrates a nonsquare fabric. The white pixel line overlay marks the angles of the warp and the filling. The angles between the two yarns were measured automatically using the image analyzer. The filling-to-warp angular measurement (i.e., the degree error, or the root mean square of 90° minus the angular measurement), the air permeability, and the distance across the dryer fabric are all given in **Table III**. These data were then used to plot air permeability and the squareness error across the fabric, as seen in **Fig. 10**. The results in Fig. 10 show that permeability is inversely related to the squareness error. The lower the filling-to-warp squareness error, the greater is the air permeability.

To establish an equation relating fabric squareness error to air permeability, the two were regressed with

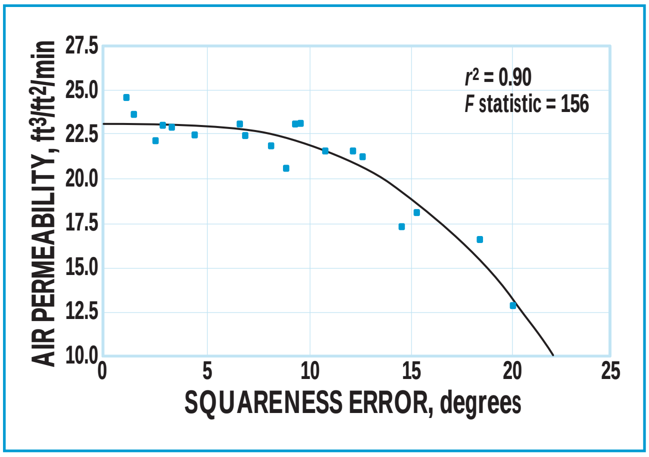
	38 caliber [b]	264 caliber [c]
Total area, $in.^2$	8.27587	0.137131
Perimeter, in.	12.0457	1.67428
Circularity	17.5329	20.4418
Major axis length, in.	4.22590	0.602425
Breadth, in.	3.09769	0.327825
Actual bullet area, $in.^2$	0.113411	0.054739
Avg. target bullet area, $in.^2$	0.827587	0.045710

[a] Bullet groupings are illustrated in Figs. 15 and 16
[b] Revolver (Smith & Wesson) using 168-grain bullets (cast No. 2 alloy) with 3.3 grains gunpowder (Bullseye); target distance 50 yd
[c] Rifle (Remington model 700 BDL) using 100-grain hollow-point bullets (Sierra) with 59 grains gunpowder (IMR 4350); target distance 100 yd

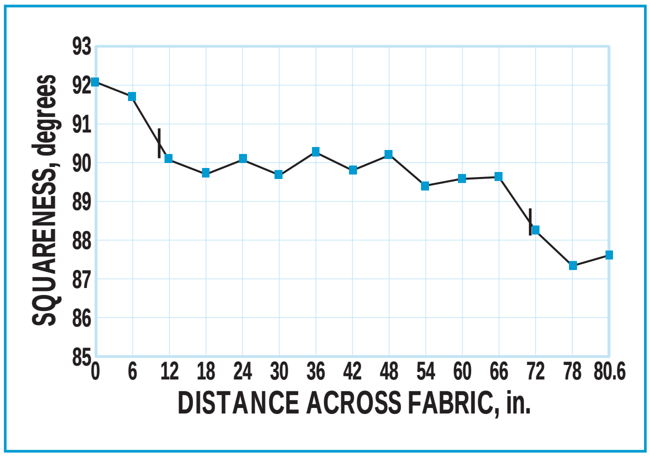
IV. Measurements of bullet groupings [a]



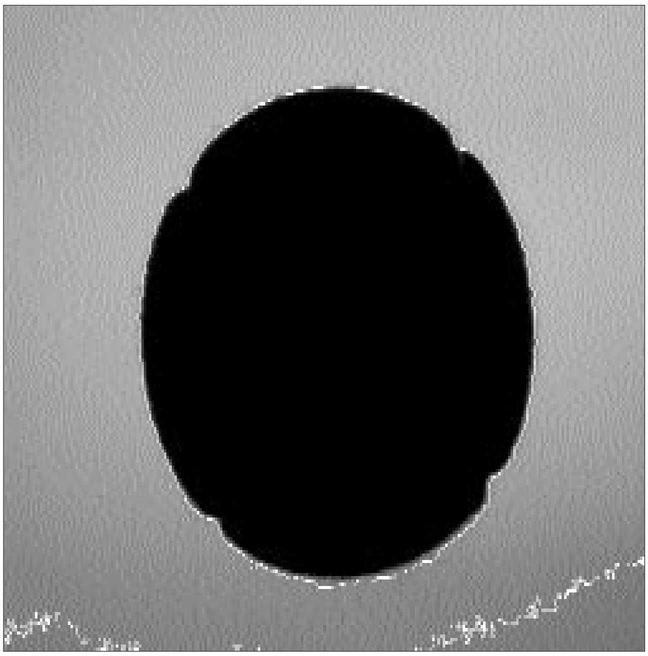
10. Relationship between fabric squareness error and air permeability



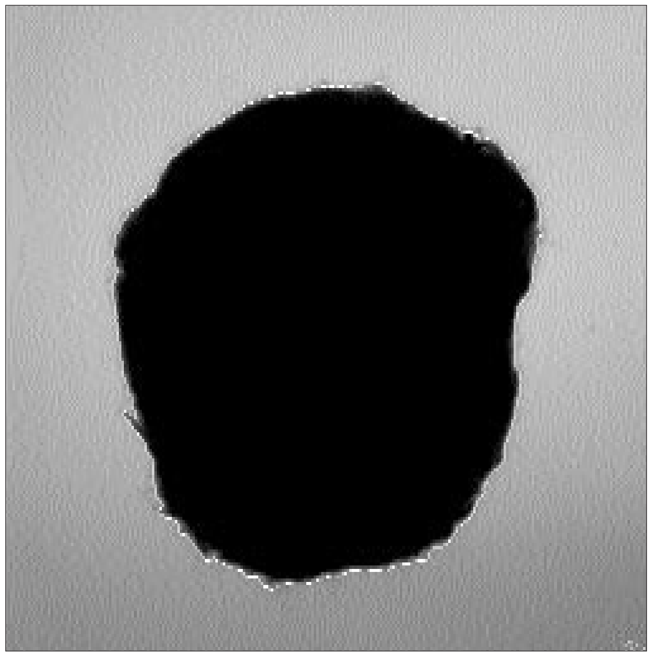
11. Least-squares fit of fabric squareness error with air permeability



12. Screen squareness at intervals across the fabric



13. New tennis ball silhouette with a pixel outline for data collection



14. Ragged tennis ball silhouette with a pixel outline for data collection

each other. **Figure 11** illustrates the graph obtained. The resulting equation is:

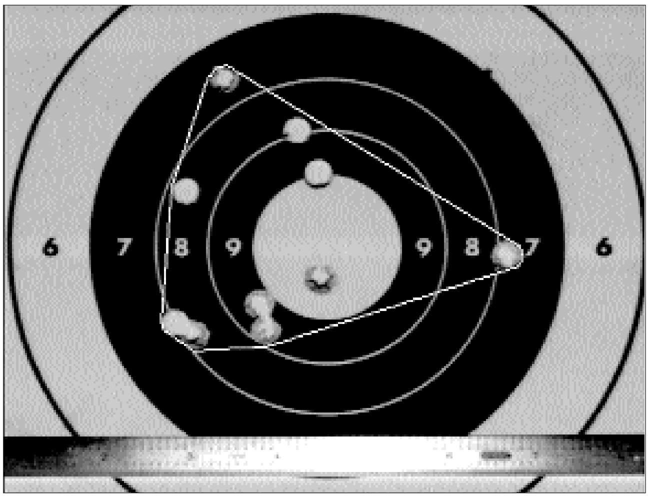
$$Y = 23.055 - 0.0012337x^3 \quad (5)$$

where Y is the air permeability and x is the degree of fabric squareness error. With an r^2 value of 0.90 and an F statistic of 156, the fit is excellent. Thus, permeability is inversely proportional to the third power of the squareness error.

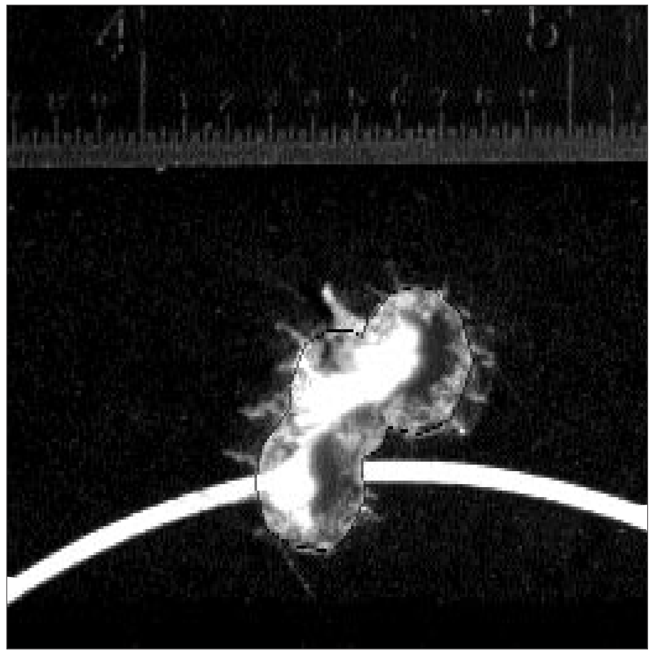
Another example where fabric squareness was found to be of importance was with large commercial window shades and large projection screens. These shades and screens were designed to be rolled up and let down using electrical power. However, the edges of some screens and shades were found to telescope when they were rolled up. That is, the screens did not track, so the edges in multiple layers of fabric did not lay one upon the other in a straight fashion. This caused the shade or screen to jam, tearing the edges, wrinkling the fabric, and sometimes damaging the windup motor because of the excessive load imposed on it.

Using the image analyzer, the squareness of the fabric was determined on the shades and screens that had operated poorly. **Figure 12** illus-

KEYWORDS
Fabric, image analysis, nonwovens, quality control, trouble shooting, yarn.



15. Ten-round target group (38-caliber revolver at 50 yards) with a pixel outline for data collection



16. Three-round target group (264-caliber rifle at 100 yards) with a pixel outline for data collection

trates the squareness of one of these across the fabric. (A fabric with a squareness of 90° was considered perfect.) It can be seen that the fabric at 12 in. from the edge to 66 in. inwards from the same edge, is very close to 90°. It is also apparent that the left edge at 1 in. and 6 in. was not square. The fabric right edge at 72 in., 78 in., and 80.6 in. also was not square. The nonsquare fabric was found to be the cause of improperly operating screens. To correct the problem, the fabricator should demand that the supplier only ship fabrics that are square. The alternative would be to use only square fabric and discard materials that are not square. However, the latter would generate an excessive amount of waste.

TENNIS BALLS

Initially, tennis balls were made using fulled woven woolen fabric that often used a six-harness irregular satin weave. The scales on the wool fiber enable the fabric being fulled to produce the thick, dense fabric for the tennis ball's outer surface. The long floats of the weave enabled a nap to easily be raised to produce the felt-like surface. Nylon and polyester fibers can be used to produce cheaper fabrics with greater abrasion resistance. However, because nylon and polyester do not have scales, these fibers will not full. Instead, the fabrics are needle punched to achieve the proper integrity and felt-like surface characteristics.

An image analyzer can be used to determine the ball size and seam uniformity. In addition, the image analyzer can determine the amount of abrasion, circularity, and the extent of the pebbly or pilling texture of the ball.

Abrasion of the ball is easily measured by determining the ball area when backlighted immediately after removal from the tubular shipping container and again after a prescribed time of usage. For example, three pro tennis balls from one manufacturer had a silhouette area of 3746 mm^2 when backlighted. Once the initial silhouetted area is a known quantity, the rate of abrasion can be determined by periodically remeasuring the balls after a known amount of usage. A uniformly wearing ball will get progressively smaller because of the loss of fiber through abrasion.

Sometimes a tennis ball can begin to fray, peel, or become ragged. The best way to measure this is by determining the circularity of the ball. If the ball was perfectly circular, the numerical value would be 12.57 as determined by Eq. 6.

Distance across fabric, cm	Fabric squareness error, degrees	Fabric air permeability, $ft^3/ft^2/min$
10	1.44	23.57
20	2.49	22.08
30	6.62	22.99
40	9.56	22.99
50	12.66	21.14
60	18.45	16.46
70	10.82	21.46
80	15.29	18.02
90	20.07	12.79
100	14.51	17.26
110	12.66	21.14
120	12.17	21.46
130	9.36	22.99
140	8.18	21.77
150	8.95	20.49
160	6.86	22.39
170	4.45	22.39
180	3.28	22.84
190	1.10	24.57
200	2.89	22.99

III. Fabric squareness error and air permeability across screen fabric

$$\text{Circularity ratio} = \frac{\text{perimeter} \times \text{perimeter}}{\text{area}} \quad (6)$$

$$= \frac{2\Pi R \times 2\Pi R}{\Pi R^2}$$

$$= 4\Pi$$

$$= 12.57$$

where R is the ball radius and 12.57 is a dimensionless number. The same three pro balls had an average circularity of 14.49. A silhouette of one of the new tennis balls is shown in **Fig. 13**. Since 12.57 is the minimum circularity value that could be obtained for a perfectly circular area—and if we assign a value of 100% to represent this minimum circularity—then the average circularity value of 14.49 for the new pro balls is 115.27% or a 15.27% circularity error. The ragged ball shown in **Fig. 14** has a circularity of 16.3276, or a circularity error of 29.89%. The error value of the ragged ball is nearly twice that of a new pro ball.

The degree of tennis ball pilling or surface roughness can be determined by uniformly lighting the surface of the ball. After setting the threshold lighting value, the number of light and dark areas within a specified area could be established. The result could then be compared with a good ball using a suitable equation.

TARGET SHOOTING

Image analysis can even be used to improve the accuracy of a hobbyist who enjoys target shooting. It is possible to improve target accuracy by experimenting with the various commercially available bullets or even with homemade bullets using a range and amount of powder types. I enjoy trying to improve the grouping of 10 rounds fired at a target using a particular set of loading variables.

Figures 15 illustrates the grouping of ten 38-caliber rounds fired at 50 yards from a revolver. **Figure 16** illustrates a three-round grouping of 264-caliber bullets fired at 100 yards from a rifle. Image analysis results for both groupings are presented in **Table IV**. Using baseline data such as this, one could assess the effects of changing powder type or weight (or other variables) on target accuracy.

CONCLUSIONS

An image analysis system with appropriate software is a very useful tool for making measurements, analyzing materials and products, and determining the effects of variables on products and processes. The application and use of an imaging system and software is virtually limitless. However, the utility of the data obtained depends on the system and its software, the appropriate use of lighting, the system's optics, the statistical methods used, and—to a large extent—on the skill and knowledge of the operator. TJ

J. Robert Wagner is president of J. Robert Wagner & Associates, 2996 Runnymede Drive, Norristown, PA 19401.

Received for review Oct. 15, 1996.
Accepted Sep. 5, 1997.
Presented at the TAPPI 1997 Nonwovens Conference.

LITERATURE CITED

1. Wagner, J. R., *TAPPI 1994 Nonwovens Conference Proceedings*, TAPPI PRESS, Atlanta, p. 155.
2. Wagner, J. R., *Tappi J.* 76(4): 190(1993).
3. Wagner, J. R. and Hager, H.A., *TAPPI 1996 Nonwovens Conference Proceedings*, TAPPI PRESS, Atlanta, p. 303.
4. "Optical yarn classification and quality management," ITB Yarn and Fabric Forming, Zurich, Switzerland, 1996, p. 30.
5. Wagner, J. R., "Fabric studies," J. Robert Wagner & Assoc., Norristown, PA, 1992.
6. "Smoothness of seams in fabrics after repeated home laundering," AATCC Test Method 88B-1992, American Association of Textile Chemists and Colorists, Research Triangle Park, NC, 1992.