LINEAR IMAGE DETECTOR-BASED EDGE SCAN SENSOR

by

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ABSTRACT

It has always been problematic to accurately sense a nonwoven (spunbond) material edge by an analog photoelectric or ultrasonic means. A sensor based on analog photoelectric or ultrasonic detection determines the lateral displacement of the web by measuring the amount of signal the web blocks. For opaque materials, this sensing technique is sufficient with some concerns about the environmental effect on the detector, as well as the sensor linearity, depending on the size of the detector that is derived from the sensor proportional band requirement. However, for nonwoven materials with varying degrees of web opacity, the above-mentioned sensing scheme does not reflect accurate edge sensing by measuring the amount of signal the web blocks as seen by the detector. The light or ultrasonic signal from the transmit side can easily penetrate the nonwoven loosely bound area without any signal attenuation and can, therefore, cause the analog detector to see an average value of the signal it receives. The average received signal varies due to web opacity variations, and cannot be used to produce an accurate representation of the edge of the web. Also, frequency response of the analog detection circuitry dictates how much error it will generate based on the effect of web speed, as well as opacity variations. The slower the detector response, the less variation due to web opacity it sees for higher web speeds. Again, a slow detector response is undesirable in high-speed guiding and slitting applications.

Our goal is to design a photoelectric sensor for accurate edge sensing of nonwoven materials by disregarding the influence of web opacity variations. It also needs to be highly immune to environmental factors such as temperature and contamination, etc. The proposed method uses a digital linear image detector-based edge scan sensor in conjunction with collimated infrared light source. The light source is applied to the web in a retroreflective configuration by using a 180-degree light foldback prism. To prevent detection error due to opacity variation, this method uses a first edge detection technique. In this way, the sensor only responds to the true edge of

the web and may avoid problems related to the light source passing through the material.

THEORY OF OPERATION

As mentioned, analog detection with a through beam configuration based on infrared light is sensitive to variation in web opacity. Our proposed method to overcome this problem uses a single aspheric lens with an infrared (IR) emitter source focused upon an ashperic lens. This, in turn, generates a collimated light curtain projected in the gap of the sensor. Unlike traditional through-beam configurations, the light is then passed back to the image receiver via a 180-degree light fold-back prism creating two parallel, adjacent light paths through which the web may pass as shown in Figure 1.

To create a wide proportional band for the sensor with minimal expense, a single IR emitter and single lens setup is desired. Multiple emitters or multiple lenses to extend the width of the proportional band are undesirable because of the increased expense to compensate for greater discontinuity between lenses and emitters, thereby increasing the signal processing and sensor assembly requirements. The single IR emitter was chosen so that the radiation pattern incident on the lens from the emitter at the back focal point of the lens creates a consistent intensity distribution to obtain a wide proportional band sensor field of view. A greater proportional band may be achieved by wider lenses, but also requires a much greater focal length between the IR emitter and the lens which greatly increases the size of the sensor and the amount of power required to drive the IR emitter. A suitable compromise has been chosen. The IR LED emitter and lens in Figure 2 shows this concept.

By using a 180-degree light fold-back prism, the light source is projected across the sensor gap, folded back by the prism, and then directed back to the image detector. In this scheme, the light signal travels in two parallel, adjacent paths accomplishing a greater amount of signal attenuation at the nonwoven web effectively increasing the step size between web presence and absence as compared with through beam single-pass operation. The traditional retroreflective approach uses the same light path for signal transmission via a 50% beam splitting mirror causing a minimum signal loss of 75% at the detector. Our proposed method uses two separate light paths for transmission and reception allowing a much higher signal-to-noise ratio. The prism is assembled using two highly reflective, first surface mirrors mounted at 45-degree angles off the horizontal. Mirrors are used as opposed to an actual prism with reflective surfaces to reduce the amount of light attenuation caused by the prism, as well as providing for more cost-effective assembly. The mirror assembly is shown in Figure 3.

In the last step, the light is received at an image detector consisting of an array of multiple photodiodes (called pixels) in a row. The photodiodes accumulate charge corresponding to the intensity and length of time that light is incident upon each photodiode. When this array is scanned, each photodiode transfers the amount of charge it contained to the output pixel by pixel in a serial manner. This serial stream of pixel charges creates a video signal that can be judged and processed to find the edge of the web. Converted by an A/D converter and processed in real time, the sensor control unit or controller can then create a sensor output based upon the video signal and web position. Figure 4 depicts a video signal that may be received when a nonwoven web is present in the sensor field of view.

Digital processing of the video signal allows the sensor to fully process the data and create its output based upon the first edge of the material as opposed to an output based upon the total amount of light received. This edge is threshold-based and creates immunity to any opacity variations in the material and can even disregard small holes in the material after the edge has been found as seen in Figure 4. A pixel is considered high if its magnitude is greater than that of the set threshold. Otherwise, the pixel is considered low. The web edge is found by the controller by comparing adjacent pixels to the threshold. When a transition from a high pixel to a low pixel is found, the controller will then begin monitoring the pixel filter logic. The transition will be considered a valid web edge if the number of pixels remaining low following the transistion is greater than the number of pixels determined by the pixel filter size. In the figure, the solid horizontal line represents the pixel threshold level. As the video signal transistions from above to below this threshold, the controller uses the size or width of the pixel filter to judge if the transistion is a valid edge. If the edge is valid, the output of the sensor is updated and any further transistions in video are ingnored. Furthermore, the pixel filter and threshold levels are adjustable and may be configured to filter out variable amounts of contamination and debris in the sensing field of view. Debris in the sensor field of view more narrow than the pixel filter can then be disregarded.

Because of the first edge detection processing scheme, the sensor is now capable of sensing nonwoven and opaque materials with no setup changes. Figures 5, 6, and 7 may be compared for illustration of an opaque material versus both nonwoven and screen-type material video signals. As seen in these figures, the nonwoven material allows light to pass through and to be seen at the image detector where the opaque material completely blocks the light. In Figure 6, the light passing through the web is attenuated by the double-pass operation to a level below the adjustable pixel threshold. Figure 7, shows a screen-type web and corresponding video. With this web the first edge is found because the first strand in the screen is wider than the adjustable pixel filter. All holes in the material passing light after this edge and all debris in the field of view smaller than the pixel filter are disregarded. The sensor controller is capable of detecting the proper edge in each of these webs independent the variation in these materials. It is able to disregard the light passed through the nonwoven material and the holes in the screen-type material, producing a valid output for each web, as well as detecting the edge transition of the opaqe web in the same manner.

For transparent web edge detection, we need to record each pixel's nominal unblocked output and each nominal fully blocked output. In this way, we can normalize each pixel according to its maximum and minimum values for a particular material. By using a sensor with memory components, the no web pixel output for each pixel may be recorded by the sensor, as well as the fully covered pixel output. When the sensor is operating, a gain and offset may then be applied to each pixel in real time to find the corresponding normalized pixel output as shown in the following equations:

$$Pval_i = P_i * Pg_i + Po_i \; ; \quad 1 \le i \le N$$

$$Pg_i = \frac{1}{P\max_i - P\min_i}$$

$$Po_i = -\frac{P\min_i}{P\max_i - P\min_i}$$

Where:

Pval = current normalized pixel value
P = current pixel input value
Pg = current pixel gain
Po = current pixel offset
i = current pixel number
Pmax = no web pixel value
Pmin = full web pixel value
N = number of pixels in detector

Using this normalized pixel value, a common threshold can be applied to every pixel to detect a transition for web edge detection in the same manner as described for opaque and nonwoven materials.

MAIN RESULTS

In this sensing scheme, the experimental results show that the video signal received in the case of low opacity, nonwoven material can be used to find the web edge in the same manner as edge detection on a video signal of an opaque web.

The laboratory results show an analog IR photoelectric sensor gives 24% to 47% signal change when it is fully covered with nonwoven materials because it shows the variation in opacity that it detects. Figure 8 shows a linearity plot of a typical analog sensor with both an opaque web and two different weight grades of nonwoven web materials plotted. As can be seen, not only does the nonwoven data appear to lose linearity, the signal amplitude varies greatly compared to that of the opaque material. On the other hand, in the proposed sensing scheme, 100% signal change is achieved for the fully covered sensor field of view with nonwoven or spunbond material as compared to the opaque material. The plots in Figure 9 show opaque materials and different weight grades of nonwoven materials on a single plot. The data was created using the same sensor by linearity tests on each material with no setup or configuration changes made. As seen in the plots, the nonwoven materials behave nearly exactly as the opaque material for the proposed sensing scheme. As stated, no setup time is required to change detection configuration from nonwoven or opaque materials, reducing time and cost for customers.

CONCLUSION

As discussed, traditional analog photoelectric and ultrasonic sensors have varying degrees of sensor output error with varying degrees of web opacity. To compensate the effect of web opacity variation, the traditional approach has been to calibrate sensors manually for each web or switch to camera-based digital edge detection techniques. The manual sensor calibration can only be used with homogeneous webs to become an effective means for opacity variation compensation. In practice, most of the nonwoven materials are not homogeneous and vary in opacity. On the other hand, the camera-based digital edge detection technique requires illumination, an optical camera iris, focus, and zoom adjustments to improve accuracy in measurement. This required setup before every new material guiding can be time-consuming, which means it can be expensive for the customer. In addition, the camera setup is not immune to plane change error because of conical camera field of view. A camera-based web edge detection method is also put at a disadvantage by requiring a larger sensing gap to obtain the desired field of view, which may be a problem in some applications where space is limited.

The sensing scheme proposed, based upon a fixed, small sensing gap with a wide field of view ensures compactness and ease of use. By using the 180-degree light fold-back prism, creating a double attenuation of the light path across the web, this technique is superior to through beam optical sensing techniques. This particular sensor can be used in edge detection for most applications such as transparent, nonwoven, and opaque materials. Since detection is based on first edge only, it can be used on some photosensitive materials where printing is present in a transparent film. It can allow some level of sensor contamination as well because detection of the edge is based on a truly digital threshold comparison technique. Because web detection in the sensing gap is based on IR light, variations in air characteristics and temperature will not affect operation. In addition, the sensor detection scheme is threshold-based and therefore is immune to amplitude variation of the video signal. Debris falling into the sensor field of view can be ignored with pixel filtering and, in some applications the wide field of view will accommodate some web width variations in center guiding mode without repositioning the sensor. The wide field of view is accomplished using an array of high-resolution photodiode pixels having a lower capacitance than that of large photodiodes used in analog applications. Therefore, we can achieve a higher sensor response compared to traditional analog photodiode-based, wide field of view sensors. Because of the collimated light signal, the web plane change immunity is superior to that of through beam and camera-based detection techniques, as well as saving time and cost in setup.

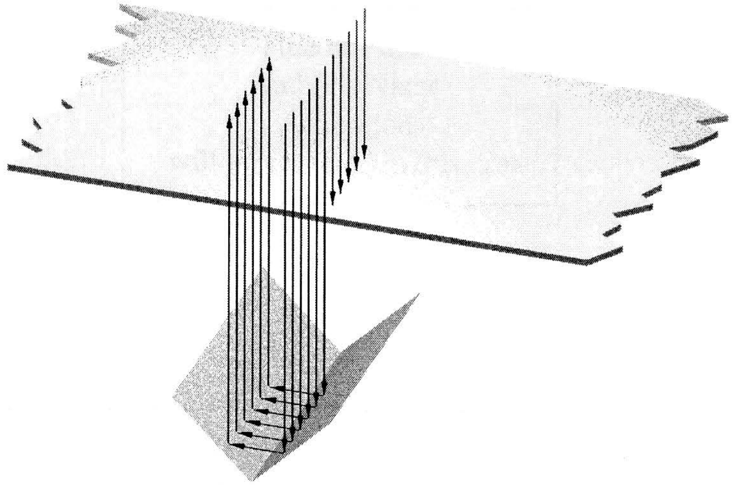

Figure 1: Web Blocking Adjacent Light Curtains

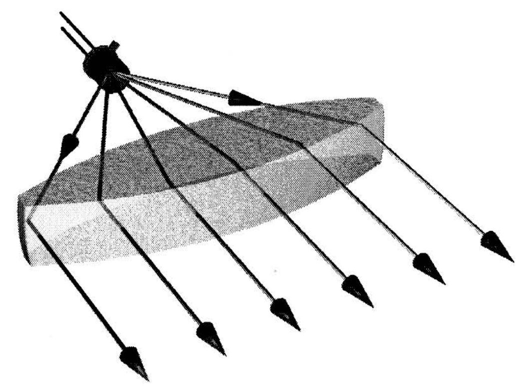

Figure 2: IR Emitter and Collimating Aspheric Lens

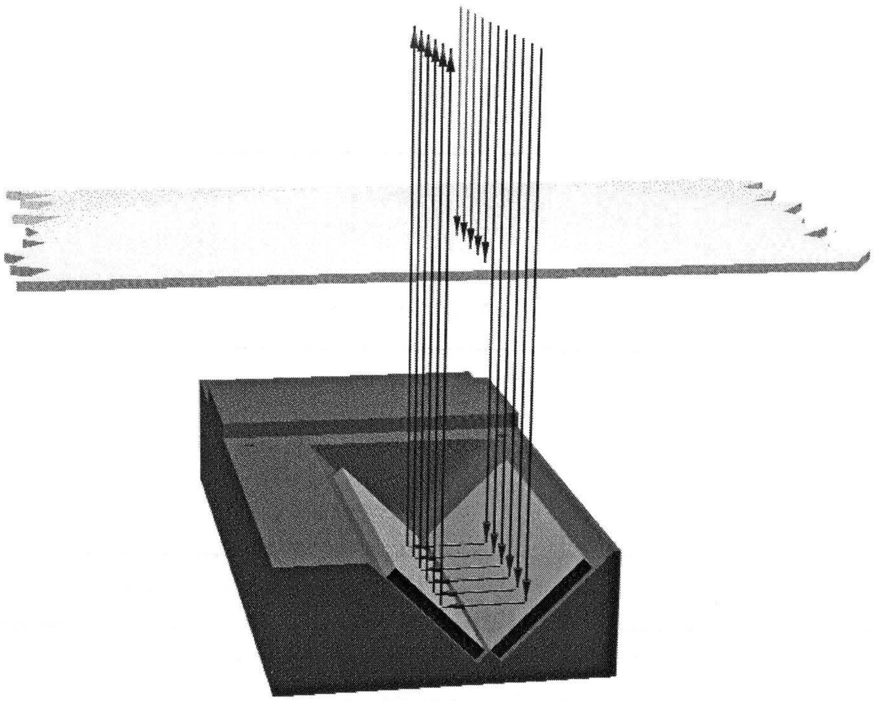

Figure 3: Mirror Assembly and Light Fold Path

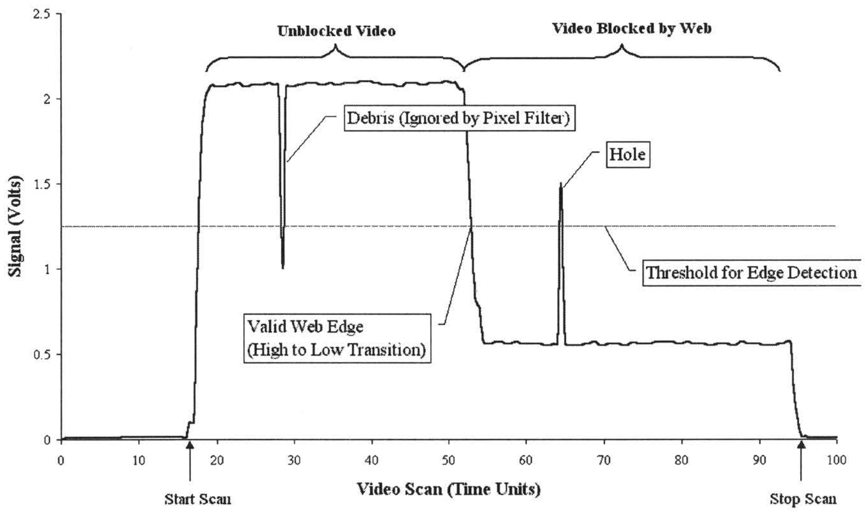

Figure 4: Nonwoven Web Video with Debris and Hole

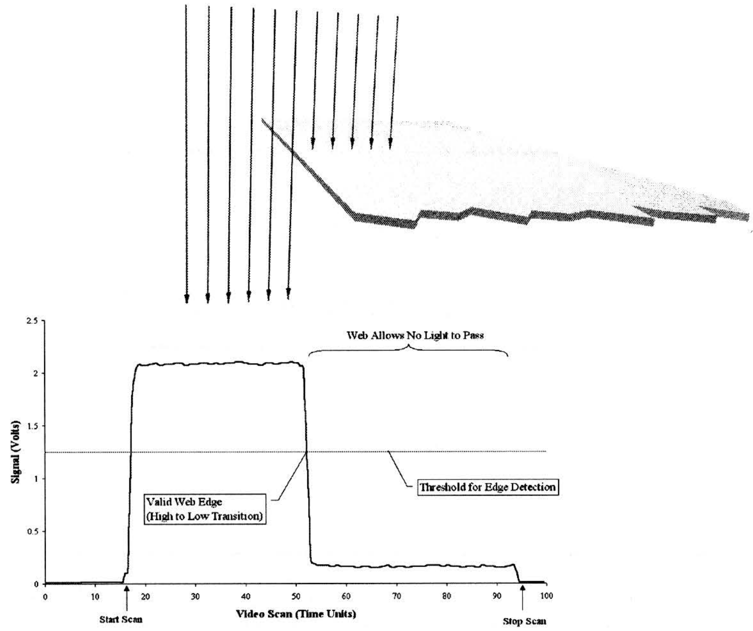

Figure 5: Opaque Web Completely Blocks Video Where Present

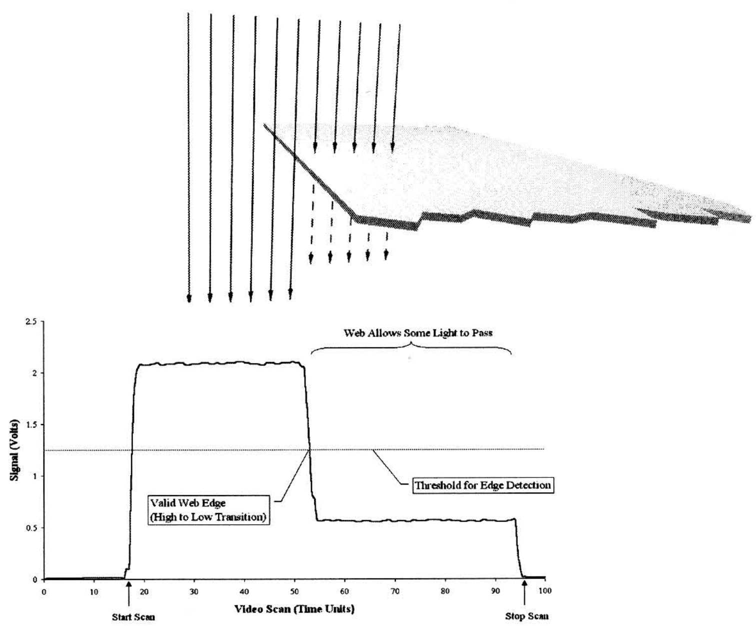

Figure 6: Nonwoven Web Allows Some Light to Pass Through

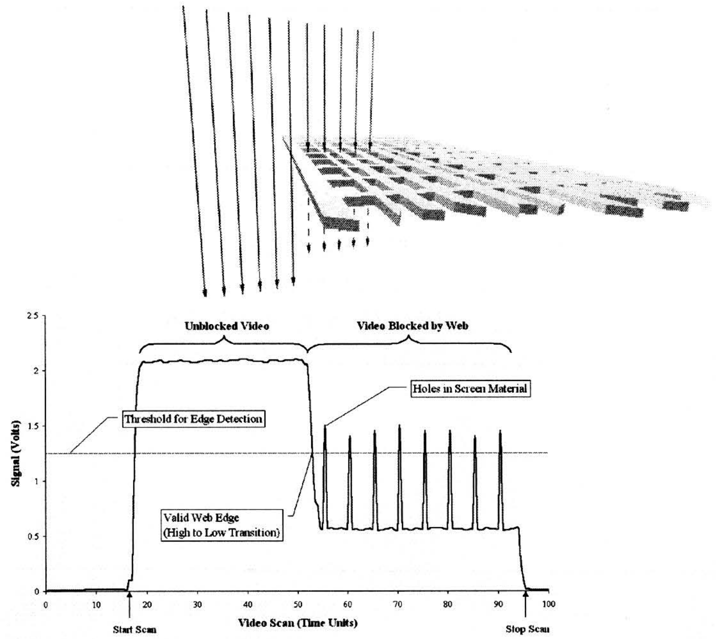

Figure 7: Screen Web Allows Light to Pass Through as Holes

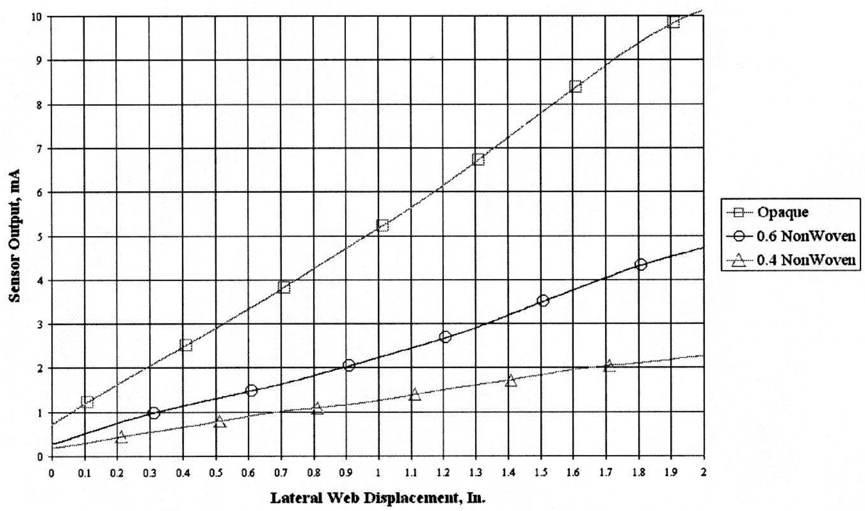

Figure 8: Analog Sensor Linearity Plots

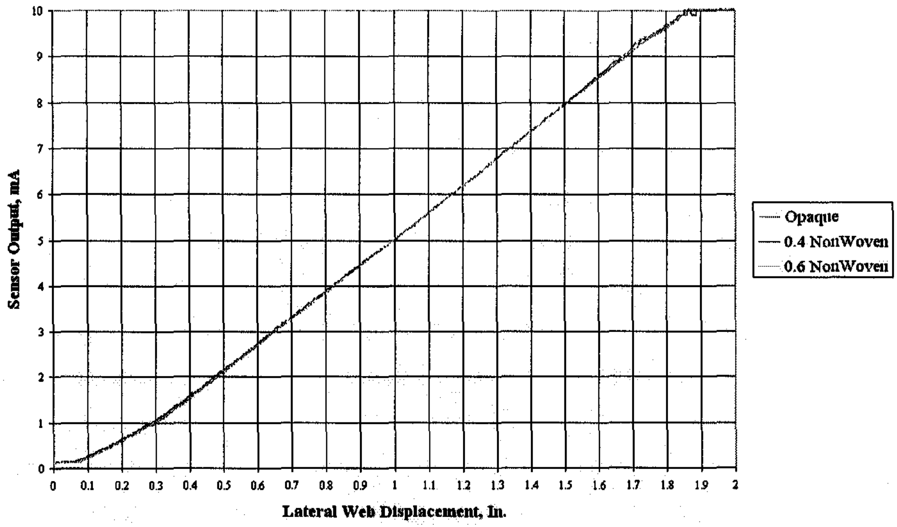

Figure 9: Digital Edge-Based Detection Linearity Plots

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Name & Affiliation	**Question**
R. Swanson – 3M	I was wondering about the specifications in terms of resolution. Also what is the stability, linearity, etc.?
Name & Affiliation	**Answer**
J. Haque – Fife Corporation	The resolution is 2.5 thousandths of an inch.
Name & Affiliation	**Question**
J. Brown – Essex Systems	How does the cost of this sensor compare with that of an analog sensor that would be of equivalent proportional bandwidth?
Name & Affiliation	**Answer**
J. Haque – Fife Corporation	Yes, I'm comparing mainly to the camera based sensors because we are using a digital sensor technique. If you compare camera-based sensors, this sensor is a lot cheaper. It is a stand-alone system and everything is self-contained. A lens or illumination adjustment are not required. Compared to a camera-based system, this sensor is definitely cost effective. If you compare to analog systems there are many analog systems. There are solar cell and photo diode based systems and this system is a bit expensive compared to those.
Name & Affiliation	**Question**
J. Brown – Essex Systems	Do you have any plans to apply this technique to printed markings?
Name & Affiliation	**Answer**
J. Haque – Fife Corporation	That's the next step, currently we have a linear array. If we choose a matrix array of photo diodes we can discern printed marks.
Name & Affiliation	**Question**
A. Konnerth – Parkinson Technologies	You had mentioned that you tried this on screens and netting, how coarse were they?
Name & Affiliation	**Answer**
J. Haque – Fife Corporation	50 thousandths of an inch.
Name & Affiliation	**Question**
A. Konnerth – Parkinson Technologies	Would you expect it to be effective on anything coarser than that?

Name & Affiliation	**Answer**
J. Haque – Fife Corporation	Yes, because you can change your pixel filter window. Since our resolution is 2.5 thousandths of an inch and our range of adjustment is 255 times 2.5 thousandths of an inch. You can discern a very narrow thread to the higher thread. A thread is defined as 4 pixels. So a thread can be as narrow as ten thousandths of an inch. The proportional band we have for the sensor is 1.7 inch so you can ignore 1/4 and 1/2 inch holes easily.