LINEAR EDGE SENSOR

by

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ABSTRACT

In modern industrial process controls, web guiding is becoming very demanding due to variations in web materials, variable web widths, and the need for better guiding accuracy. Selecting the appropriate sensor for various types of web materials and repositioning the sensors for variable web widths can be very expensive and time-consuming. At present, some web guiding applications where wide web width variations are desirable, require the sensor positioner to electromechanically reposition the sensors to accommodate the web width variations. With time, a system using electromechanical means suffers in terms of reliability and consistency in guiding accuracy.

To address these needs, a solid-state, laser-based, multiprocessing sensing scheme can be a viable option. This new sensing technique is based on a segmented, multiple transmit-receive pair scanning topology. A wide sensor field of view is achieved by staggering multiple sets of transmit-receive segments. On the transmitter side, a collimated light curtain is obtained by using a set of cross cylindrical lens-based optics with a semiconductor laser diode. Each receiver segment is made of a linear photodiode array that is independently scanned by a dedicated microcontroller. The main sensor synchronizes multiple segment scanning, processes segment information, delivers output based on web edge position.

SENSOR ARCHITECTURE AND DESCRIPTION

The architecture of the sensor (Figure 1) is divided into three major blocks: (1) transmitter block, (2) receiver block, and (3) main processor block as shown in Figure 1. A description of each block and associated operations are as follows:

Transmitter Block

This block consists of multiple transmit segments (Figure 2). These transmit segments are cascaded (staggered) together to provide a wide transmitted laser light signal curtain. Each transmit segment (Figure 3) has separate laser diode and driver with collimating optics. The laser diode generates laser light in the visible range at 670 nanometers of 5 milliwatts, Class IIIa type. The collimating optics in each transmit segment consists of a set of custom-designed, aspherical, cross cylindrical lenses. The laser beam is of an elliptical shape (Figure 4); i.e., the beam is wider in the major axis (horizontal) direction and smaller in the minor axis (vertical) direction. The first cylindrical lens collimizes the light in the vertical direction, but the beam in the horizontal direction is still spreading. The second cylindrical lens collimizes the light in the horizontal direction while the beam in the vertical direction remains collimized. Therefore, the outcome of this lens set is a rectangular slit of collimized light. It is important to note that the orientation of the lens surfaces is perpendicular to each other. Each laser diode driver board (Figure 5) has its own intensity control adjustment. Each laser diode driver consists of an electronically controlled on-off switch so it can be controlled independently based on the location of the web. Therefore, we can select a certain light curtain width by selecting a certain number of transmit segments.

Inputs to this block are DATA IN and CLK. The output is DATA OUT. The interconnect diagram of the laser diode driver board is shown in Figure 6. The bus shown in Figure 6 is made up of the following lines: (1) +5 VDC, (2) GROUND, and (3) CLK.

DATA IN of each board is supplied by DATA OUT of the previous board. DATA IN of the first board is connected to the segment controller of the main processor block (Figure 6). DATA OUT of the last board is not connected.

Receiver Block

This block consists of multiple receive segments. Each segment has a separate linear photodiode array (linear image sensor) (Figure 3) which is scanned independently by a dedicated microcontroller. This block (Figure 7) performs array scanning by generating clock signals on command. Because of the through-beam configuration, each receive segment is illuminated by their respective transmit segment. It detects both edges within the field of view and delivers edge data on demand. For diagnostic purposes, it also provides contents of each memory location.

Each receive segment is participating in a full-duplex network and staggered together to provide a wide sensor field of view. In the front of the field of view, there is a set of red filters with light control film that forms a grid pattern to provide ambient light immunity. The microcontroller in each receive segment is responsible for generating the START, SHIFT CLK, and PIXEL CLK signals. The PIXEL CLK is used to retrieve data from each individual pixel of the linear image sensor. The SHIFT CLK is used to transfer the video data of all the pixels to the analog output of the linear image sensor. This is known as VIDEO output. The VIDEO output is amplified before is it fed into the comparator input of the microcontroller. Each pixel of this VIDEO signal is compared to a common reference input that is supplied or commanded to generate its own by the segment control block of the main processor board. The presence of a web edge causes a transition in the VIDEO signal from its previous state at the pixel where the web edge is found. Based on this transition, the web edge location is recorded with respect to the pixel count of the linear image sensor.

The communications interface of the segment driver block is of EIA RS-485 standard where every segment driver is participating in a full-duplex network. Therefore, it can communicate with the segment control block of the main processor. There is an AUTO ADDRESS input and output line available on every segment driver board. The interconnection of this line between the segments is shown in Figure 8. AUTO ADDRESS IN of each board is connected to AUTO ADDRESS OUT of the previous board. AUTO ADDRESS IN of the first board is connected to the segment controller of the main processor block. AUTO ADDRESS OUT of the last board is not connected. The input and output lines of the individual segment drivers as are follows: (1) +5 VDC, (2) GROUND, (3) RESET, (4) AUTO ADDRESS IN/OUT, (5) RX+, (6) RX-, (7) TX+, and (8) TX-.

In summary, the basic responsibilities of the receiver block are as follows:

1. Generate the clocking signal required to drive the linear image sensor array.
2. Detect any edges present within the field of view.
3. Deliver the edge information when requested.
4. Participate in auto-addressing cycle during setup.
5. Support diagnostic functions.

Main Processor Block

This block consists of power supply and main processor board sections (Figure 9). The power supply is a universal-type that can accept a wide input range of 90-265 VAC.

The main processor board is divided into two main blocks: (1) segment controller block and (2) communication controller block.

Segment Controller

The segment controller block consists of the segment controller, D to A converter, E/I converters, and EIA RS-485 transceivers.

The basic responsibilities of this block are to:

1. Control the segment driver communication network.
2. Control the auto-addressing process (Appendix A).
3. Control the segment overlap calibration (Appendix B).
4. Initiate synchronous array scanning (Appendix A). This is accomplished by issuing a single command to all segment driver boards of the receiver block.
5. Collect edge data from the segment drivers (Appendix C).
6. Calculate actual web edge positions by correcting for the linear image sensor array overlaps (Appendix D).
7. Assign and position relocatable proportional bands for each edge (logical sensors) (Appendices C and D).

8. Generate laser on-off control (Appendix E).
9. Generate analog outputs based on both web edges. This is achieved by sending a digital value to the D to A converter that supplies a voltage input to an E/I converter. The E/I converter generates a current output. This is done for both web edges as standard sensor output.
10. Provide command interpreter and status generation.
11. Provide the main diagnostic kernel.
12. Maintain the slave portion of the SPI link with the communications processor.

Communications Controller

This block consists of the communications controller and EIA-485 transceivers. The basic responsibilities of this block are to:

1. Provide serial bus interface to the sensor.
2. SPI link master control for communication to segment controller.
3. Provide communication to PC for testing/configuration.
4. Provide secondary diagnostic kernel.

APPLICATION

This sensor can be used with any signal processor that accepts analog input. The possible applications are as follows:

1. Moving-Sensor Center Guide Mode - In this mode, the sensor will accept web width variations within the sensor field of view without repositioning the sensor.
2. Fixed-Sensor Guiding Mode - This mode is intended for guiding with either edge. The material can be placed anywhere within the sensor field of view.

This particular sensor can also be connected to a serial bus for more advanced applications where the features listed below are available:

1. Programmable Proportional Band for Either Edge
2. Relocatable Proportional Bands
3. Web Width Monitoring and Output for Other Process Controls (such as tension control)
4. Web Centerline Calculation
5. Machine Center Calculation and Calibration
6. Web Centerline Shift with Respect to Calibrated Machine Center Anywhere in the Sensor Field of View
7. Display Amount of Relative Web Centerline Shift with Respect to Machine Center
8. Nearly Instantaneous Web Seek
9. Programmable Web Centerline Shift Speed
10. User-Friendly Interface for Basic Web Guiding and Positioning

CONCLUSION

Since each transmit segment generates a collimated coherent laser light curtain with negligible divergence, a wide variable sensing gap is attainable because the intensity of the light curtain remains the same. It also provides plane change immunity throughout the sensor field of view at any web plane. Because of this segmented transmit-receive pair, the sensor size for edge guiding can be specified with respect to the receive segment pixel resolution. Although we have a wide sensor field of view, because of a programmable proportional band, we can maintain a high sensitivity for edge position error. The solid-state approach to this new sensing technique does not require any electromechanical means for sensor repositioning; therefore, system reliability is much higher.

ILLUSTRATIONS

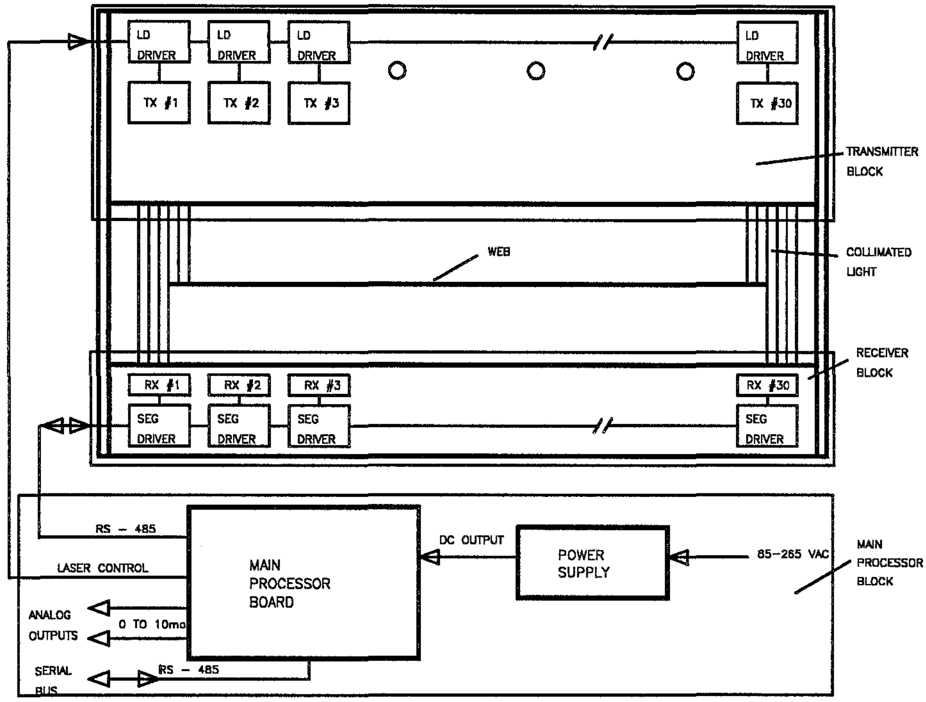


Figure 1: Sensor Architecture

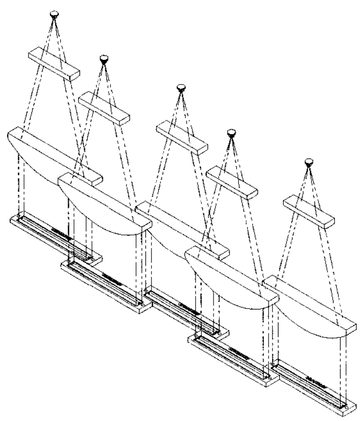


Figure 2: Multiple Transmit Segments

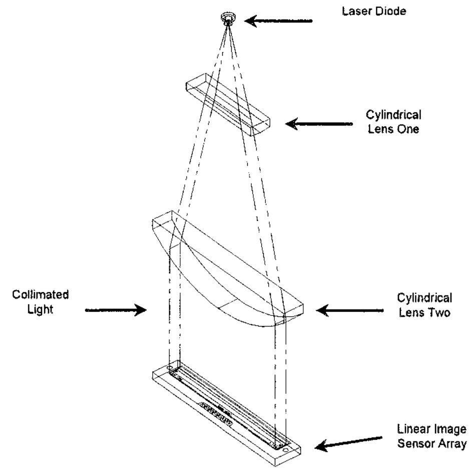


Figure 3: Photodiode Array

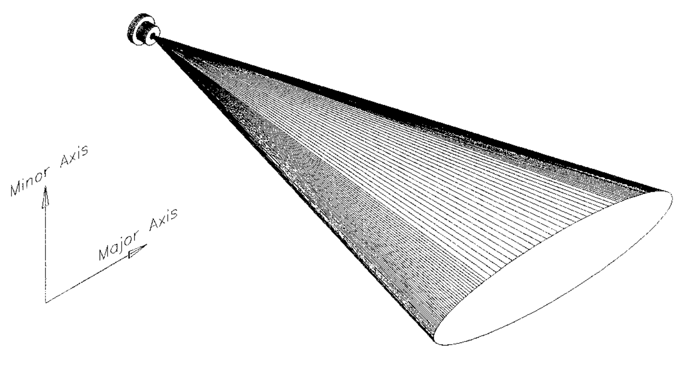


Figure 4: Laser Beam Profile

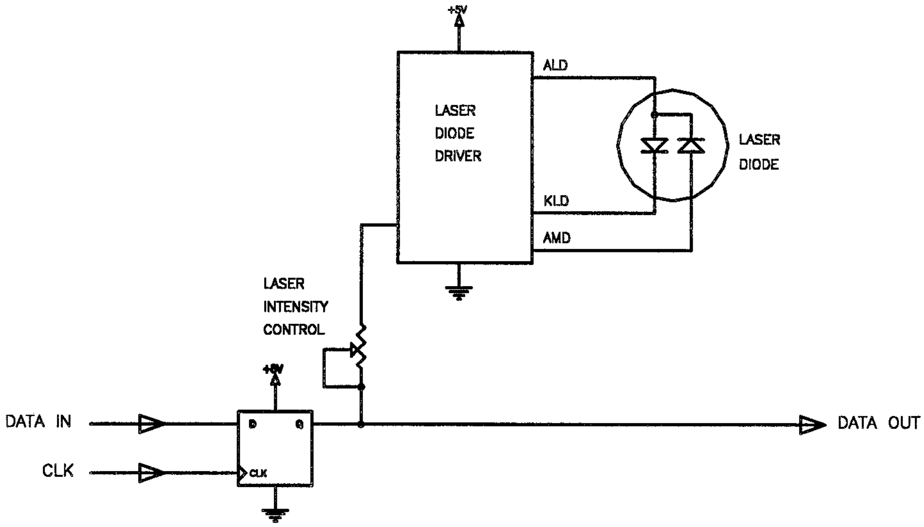


Figure 5: Laser Diode Driver

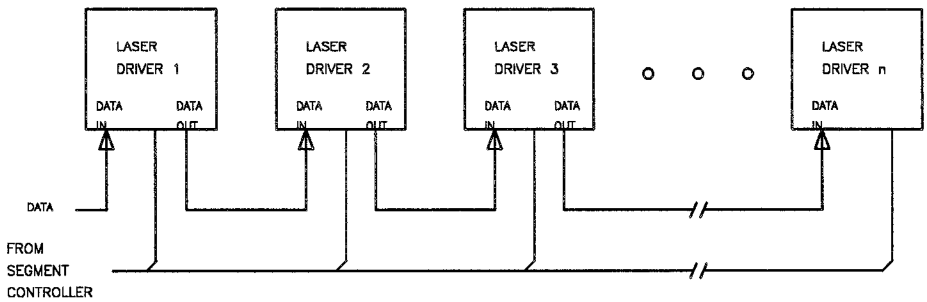


Figure 6: Laser Diode Driver Interconnection

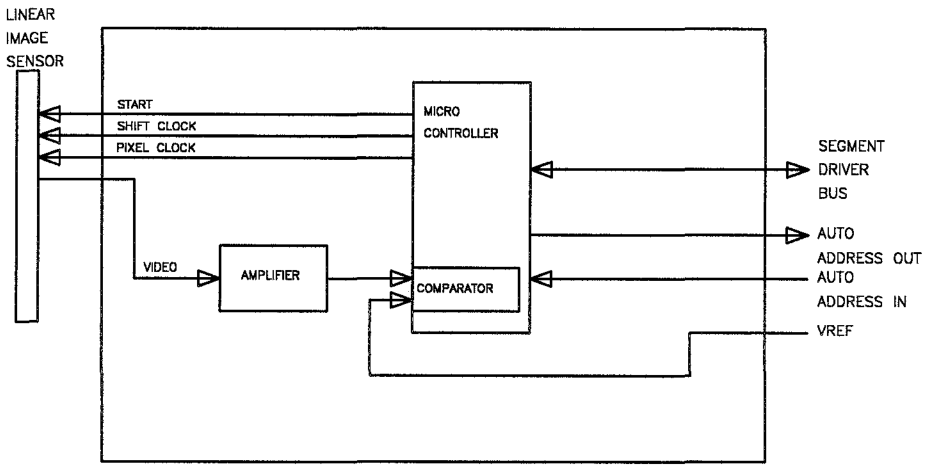


Figure 7: Receiver Block

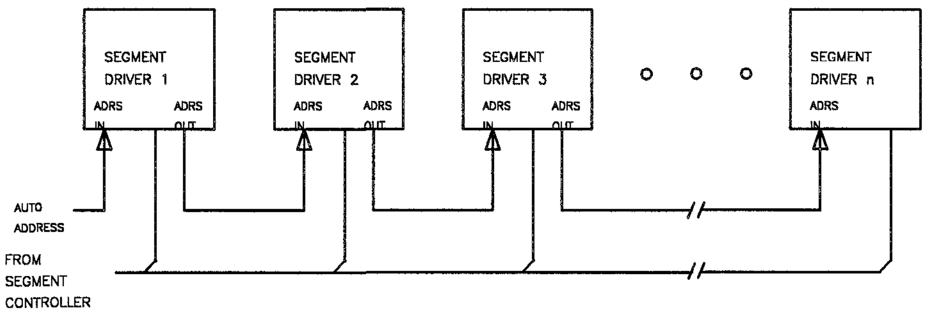


Figure 8: Segment Driver Interconnection

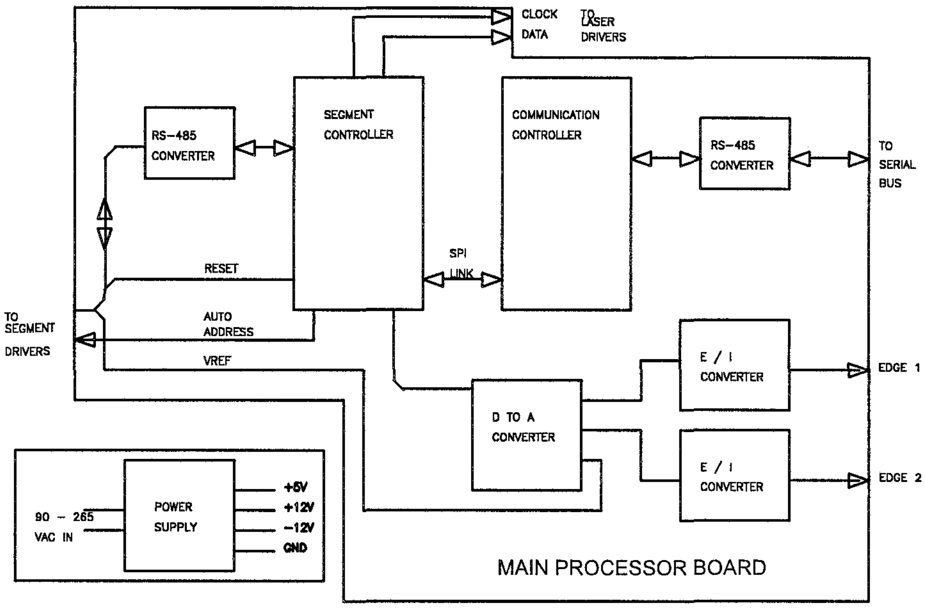


Figure 9: Main Processor

APPENDICES

Appendix A

Auto-Addressing, Because each segment driver requires a unique address to permit usage of a common communication bus, the segments must be address configurable. This is typically accomplished with jumpers, dip switches, or downloadable nonvolatile memory parameters. The auto-addressing scheme used by the segment driver requires no jumpers or unique configuration on each board. This makes them all exactly the same for ease of production, spare parts, etc. Each segment receives its address from the segment controller during the auto-addressing cycle that is done during setup. The address is stored in on-chip, nonvolatile memory. Auto-addressing is accomplished by connecting a terminal (PC running a terminal emulation program) to the sensor serial port. Power up the sensor in the diagnostic mode and, at the prompt, enter the command "A" to execute auto-addressing.

The auto-addressing description is as follows:

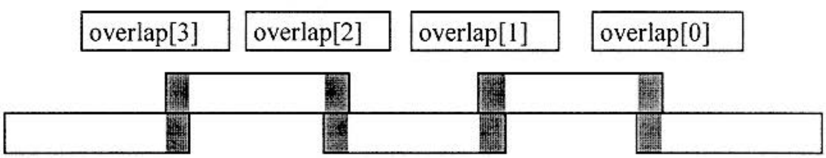
1. Segment controller issues a processor reset to all segment drivers
2. Segment drivers all turn off their LED's and clear AUTO_OUT lines.
3. Segment controller sets the AUTO_OUT line high.
4. Segment controller sends the AUTO ADDRESS command.
5. Each segment driver sets its address to 0.
6. Segment controller polls address 0.
7. Only the segment driver that detects a high signal on the AUTO_IN line responds.
8. If a segment driver responds, the segment controller sends the desired address for this segment driver (addresses are sequential from 1 to 30).
9. Segment driver stores and verifies the new address in EEPROM.
10. Segment driver responds with an ACK if successful (NACK if unsuccessful).
11. Segment driver sets the AUTO_OUT line high and turns the LED on.
12. Segment controller sends the address to the terminal display.
13. Steps 6 through 12 repeat until no more segment drivers exist that have an address of 0.
14. The segment controller records the number of segments present in EEPROM.

If a NACK is received during the auto-addressing cycle, the auto-addressing cycle is terminated with an error message. The display will contain a sequential list of successfully addressed devices. All successfully addressed segment driver will have its LED on.

Array Scanning, When the global command "START ARRAY SCAN" is received, the segment driver initiates a scan cycle on the linear image sensor of the receiver segment. This consists of generating a start pulse, concurrently with an array clock pulse. This sequence is followed by a stream of 511 clock pulses. Edge detection is achieved by monitoring the state of an analog comparator between clock transitions with respect to the threshold crossings. The scan process must always take exactly the same amount of time; otherwise, the variation in integration time in the linear image sensor will cause problems with stable edge detection. The pixel numbers where the threshold crossings occur are recorded and supplied when requested. Additionally, the presence or absence of edge information is combined into a single status byte that can be supplied quickly when requested. This single status can provide the following information with a single byte transfer: (1) segment is fully covered, (2) segment is fully uncovered, (3) left edge is present, and (4) right edge is present. This allows the segment controller to quickly locate the segment driver that has a edge within the field of view. The actual edge data is only requested if an edge is present.

Appendix B

Linear Image Sensor Array Overlap Calibration, Because of the segmented architecture, the segments must be overlapped to ensure that the web edges are not lost when traveling between segments. The segment controller must be informed how much overlap exists between segments to correctly calculate web width and web edge locations. A simple procedure exists to allow the segment controller to be "taught" the overlaps of each segment. Overlap calibration is accomplished by connecting a terminal (PC running a terminal emulation program) to the sensor serial port. Power up the sensor in the diagnostic mode and, at the prompt, enter the command "CAL." Slide the calibration tool (simulating a perpendicular web) along the entire length of the sensor field of view and monitor the PC screen. As each overlap region is passed, the PC will display the amount of overlap present. When completed, press the ENTER key on the PC. The segment controller will store the overlap values in EEPROM and in RAM. These values will then be used to compensate for each region of overlap during web calculations. A sample of a possible overlap situation is shown below for a five-segment sensor:



The overlap array is initially built based on the size of the sensor with the overlap value between each segment. It is then modified so that each array element becomes the summation of all the overlaps that precede it as shown below:

Overlap	Overlap Sum
[0] = 17	17
[1] = 13	30
[2] = 17	47
[3] = 14	61

The total logical pixel numbers can be calculated by using the following equation::

$$\text{Logical Pixel} = 510 * N - \sum_{i=1}^{N-1} OL_i$$

where, N=Number of Segments.
OL=Overlap ID.

For example, the total logical pixel for a five-segment unit with overlap (shown previously) can be calculated by using the equation shown above.

$$\text{Logical pixel} = 5 \times 510 - (17 + 13 + 17 + 14) = 2{,}489$$

Appendix C

Collect Edge Data from the Segment Drivers, The sensor will go into a web hunting mode when first powered up during no web conditions or on command. While in this mode, all lasers are turned on. Segment scanning continues as usual. Each segment driver is asked for edge type information. If edges are not found on any segment, this process continues indefinitely. Once the edges are located, the segment controller polls the respective segment drivers for the actual edge locations. At this time, the proportional bands (logical sensor) are established around the current web location. Additionally, the segment controller records the addresses of the segment drivers that are reporting edges. The addresses and actual edge locations within the segments are then used to calculate secondary target segments for each edge in case an edge is close to a segment boundary. This allows seamless monitoring of the web edges while switching segments. After each scan, a primary and a secondary segment are reestablished for both web edges. This information is also passed on to the laser control routines to keep only the segments of interest illuminated. Only the primary segments (secondary if required) are polled when tracking the web. If the edge moves to the secondary segment, it is promoted to the primary target and another secondary target is determined.

Appendix D

Linear Image Sensor Array Overlap Compensation, The segment and pixel number of a web edge tells where the edge is relative to a segment. Unfortunately, this data does not have overlap compensation applied. In order to treat the sensor as one long continuous sensor, a function to convert the segment pixel data into logical pixel is applied. The edge can be located within the range of logical pixels as a pixel number. This number can be used to determine the edge location relative to the "logical sensor" and generate the appropriate error signal. An interesting side effect of "logical sensors" is the fact that they do not physically run into each other.

Appendix E

Laser On-Off Control, After each scan, a primary and a secondary segment are reestablished for both web edges (Appendix C). This information is also passed on to the laser control routines to keep only the segments of interest illuminated. A serial bit stream is generated by the segment controller block to every laser diode driver block which converts this serial bit stream to parallel input to individual blocks to accommodate selective on-off control for each laser.

M. Haque, D. Winter, D. Hueppelsheuser, J. Newton And G. Storie
Linear Edge Sensor
6/9/99 Session 4 10:40 - 11:05 a.m.

Question - Jerry Brown, Essex Systems
I want to complement you on solving a problem I struggled with for many years when I was once in your position. Do you have any data on resolution in linearity of your sensor? Can you share any of that with us?

Answer – M. Haque, Fife
Yes, resolution is .005 of an inch right now, and linearity is excellent cause its based on the individual pixel thresholds. Like a straight line on the pixel, those pixels are like 62.5 microns. So they are very linear pixels.

Questions - Claude Faulkner, Dupont
One issue we often have in web guiding sensors is dirt and debris on sensor, I thought you may have eluded to something. Did you explain more how you deal with that?

Answer – M. Haque, Fife
We looked into that first, since we are going by the threshold base it tolerance to contamination to some degree. At the same time we're using some pixel filtering. So you can use some pixel filtering within the window. If you find some debris such as 1/4 of an in or .010 of an inch, we ignore those debris, they are not part of the web. As well as we are sensing the web threshold so it can tolerate certain levels of contamination, cause we have a wide range to choose our threshold; so yes we considered contamination in our design.

Questions - Jim Dobbs, 3M
We have a fair amount of experience with sensor exactly like your optical design; for instance Keyence makes one that's essential identical. How do you address sensing the edge of clear webs?

Answer – M. Haque, Fife
This particular scheme was our phase I of this project. We targeted opaque material. Since we are talking about 73.00 inch wide sensing so the common diode doesn't have very good resolution and linearity. That's why we have to saturate those cells a little bit more. We're thinking about Phase II to adjust the transparent issue. But this Phase I of the project we only addressed CCD array material. We're going to replace the photodiode with a better CCD array, we have an CCD array approach to detect the edge and we are already doing it in other products from our company. When you have any type of product, you have opaque material you get distinct dark to light transition; the transparent material you have a very low amount of absorption maybe 10%. So if you have the video signal which is uniform then you can determine that edge. We already have done it for the other camera signals, and we're going to do the same approach with this product to obtain the clear film guiding. That is our next phase.

Questions:
I think this is your first array sensor, isn't it?

Answer – M. Haque, Fife
No, we have other sensors using CCD arrays.

Comment:
You will have problems with pedestal flattening and everything else if your looking at 10% change in your threshold.

Answer – M. Haque, Fife
We are going to normalize them. If you do a differential with normality and you looking at the fasting, you have nothing, scan direction is important. You scan from one direction, you decide that is your edge and put anything on the print material. You can do this only when your pixels are very uniform. This is a very clear signal you can differentiate. Also we can do it another way, we can teach the web, we have a second approach. Like you can normalize the web, you can teach the web no wave and full wave, and you can normalize the sensing and you can choose the threshold 50% of the normalization. So there are several other methods that can be used to detect that transparent web. But the basic needs are pixel uniformity and better quality of the detector. That is our next phase.

Questions - Wolferman, Technical University of Munich
You can use any signal process. Are there limitations or demands on processing task frequency or something like that?

Answer – M. Haque, Fife
Depending on your application. If you are doing very simple moving sensors center guide or edge guiding, you can use any signal processor that accepts analog inputs.

Questions:
In you applications you have pointed out that you can use it for example for tension control. How can you use it?

Answer – M. Haque, Fife
Yes, not as a control but as sensor. You are getting the wave length information. So wave length means to control when it is narrow or wider so you are getting web length information out of this sensor as well as your edge guiding. So you have two outputs from this sensor ; you edge guiding as well as your controlling tension somewhere else, by monitoring it somewhere else.

Questions - Jim Cook, Delta V tech
We build vacuum coating systems, can we put this sensor in our vacuum chamber?

Answer – M. Haque, Fife
Yes, light is not medium dependent, our signal means is the light . But the problem is the optics and precision of the alignment of the optics. These are things we haven't tested yet.

Questions:
What about heat dissipation? Will the heat generated by the laser be able to dissapate?

Answer – M. Haque, Fife
Its 50 degrees C, and we're using the laser dialog of 50degrees C, we can improve the laser to 70 degrees C by buying a high quality laser. Right now we're offering 50 degree laser, and the MTF of that laser is 43000 hours at 50 degree C full output.

Comment:
You don't have much cooling in the vacuum chamber.