

[54] **INTEGRATED REFLECTANCE
PHOTOMETRIC SORTER**

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[56] **References Cited**

UNITED STATES PATENTS

3,545,610 12/1970 Kelly et al..... 209/111.7 X
3,822,362 7/1974 Weckler et al. 250/578 X

FOREIGN PATENTS OR APPLICATIONS

691,465 5/1953 United Kingdom..... 209/111.7

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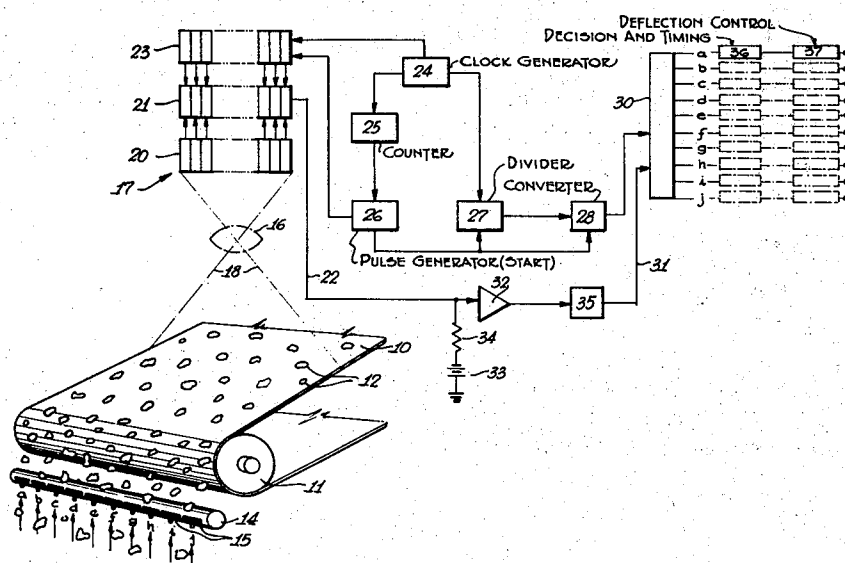
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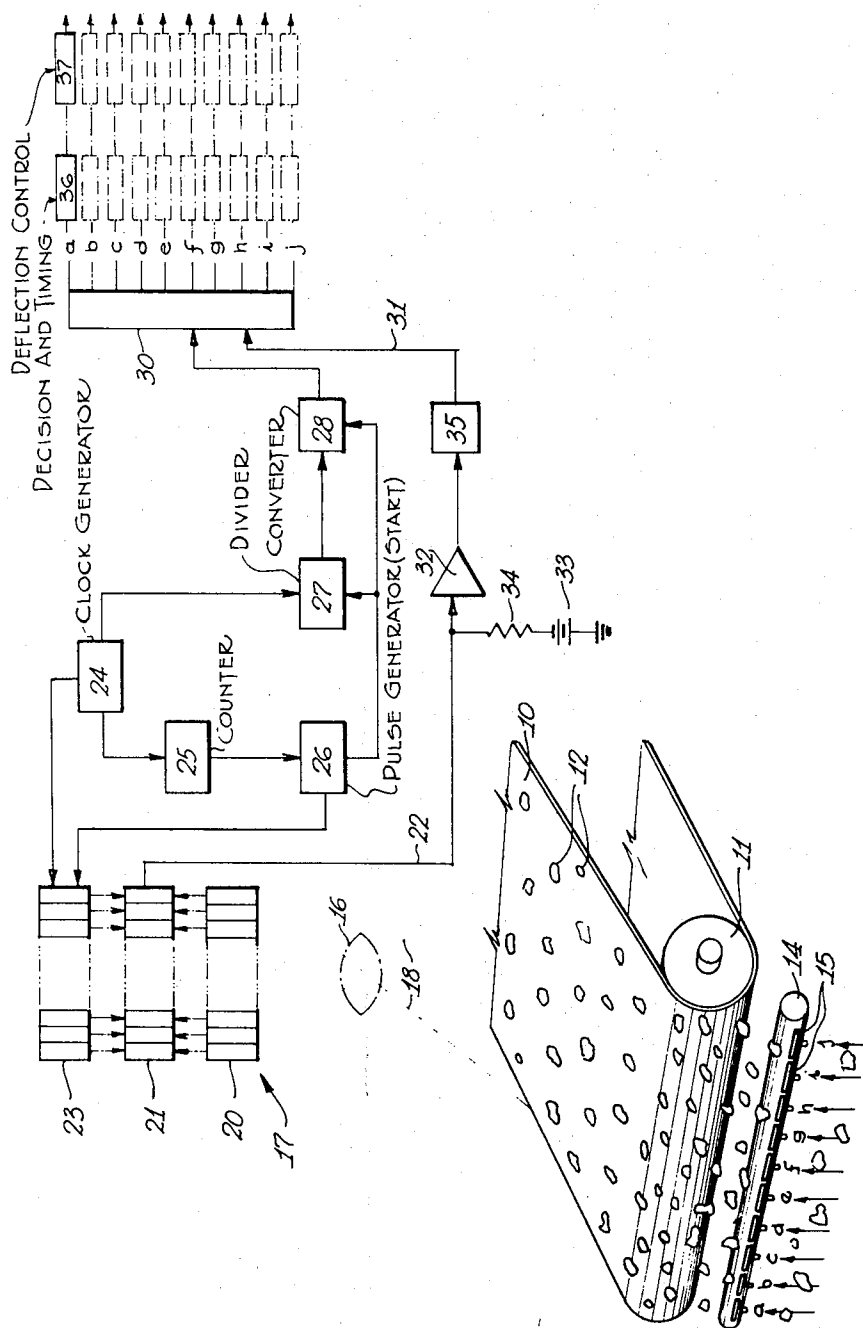
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ABSTRACT

Apparatus for sorting objects from a stream of objects moving through a sorting zone in accordance with light reflected from the objects, has a light source to direct light into the sorting zone across the width of the stream and a single line array of photodiodes each having a photosensitive semiconductor junction adapted for operation in a photon flux storage mode. An electronic switch arrangement which scans the photodiodes by connecting the output of each photodiode singly in and in succession through the array to a common output. The signal at the common output represents a succession of values of summed or integrated reflected light which impinged on each photodiode during a predetermined interval. The predetermined interval being the time period between a particular photodiode being connected to the common output on successive switching scans or sweeps. A plurality of deflection devices, such as air nozzles, is in the sorting zone downstream of the photodiodes and extending across the width of the path in side by side relationship so that each deflection device defines a channel. Timing means is provided to (a) cycle the switching arrangement and (b) provide a timing signal relating the signal at the common output to respective channels. A control circuit is connected to receive the timing signals and the signal at the common output to actuate the deflection devices to deflect objects which reflected light of predetermined characteristics.

1 Claim, 1 Drawing Figure





INTEGRATED REFLECTANCE PHOTOMETRIC SORTER

BACKGROUND OF THE INVENTION

This invention relates to an apparatus for sorting objects according to their radiation reflectance properties, and in particular according to their light radiation reflectance properties where the light radiation is intended to include infra red radiation and ultra violet radiation.

The invention is particularly adapted to the sorting of pieces or fragments of ore and will be described in connection with the sorting of ore. However, it will be realized that the invention is suitable for the sorting of other objects.

There are a number of known devices for sorting or sizing pieces of ore photometrically, and they can be classified generally into three groups according to the type of light detector used. The three groups are: (1) devices which use a photomultiplier as the light detector, (2) devices which use as the light detector a junction semiconductor operating in an instantaneous photoconductive or photovoltaic mode, and (3) devices which use a television camera tube as the light detector.

Devices falling within the first group, which use photomultipliers, generally use a lens system and a field stop to define the field of view. If scanning is used it may be accomplished by various mechanical means. For example, it may be accomplished by sweeping the field stop using a Nipkow Disc, or by sweeping the reflected or incoming radiation using a mirror drum, or by sweeping the source of radiation such as a laser beam. Occasionally both the radiation source and the incoming radiation may be swept in synchronism, as for example as described in U.S. Pat. No. 3,545,610 to Leonard Kelly et al., issued Dec. 8, 1970.

Photomultipliers achieve good sensitivity at low light levels because of their large photocathodes and internal amplification, but they have the following disadvantages. (a) Photomultipliers respond to instantaneous light levels only; there is virtually no storage or photo flux integration involved. (b) Photomultipliers have an extremely small photo current and they require great amplification in the secondary emission multiplier stage. Noise and the statistical fluctuations of photo emission and secondary emission limit the accuracy of response. (c) Scanning must be done externally and mechanically and this entails vibration, wear, limited life, and also requires a speed control or synch control. (d) Fatigue, susceptibility to mechanical damage, the requirement for a high-voltage power supply of excellent stability, cost, accuracy, and variation from unit to unit are other disadvantages.

Devices falling within the second group use as a light detector the junction of a semiconductor operating in an instantaneous photoconductive or photovoltaic mode. In this mode the output is proportional to incident light radiation at any given instant. Generally several lensed photodiodes or phototransistors are arranged in a row and are pointed directly at a light source. Objects interposed between the light source and the detectors cause output signals, of a single binary nature, related to size, plan area or profile only. The disadvantages or limitations of semiconductors used in this instantaneous photon flux mode are as follows: (a) The active area is very small. When operated

in this instantaneous mode, they require a high intensity of radiation to produce a useful output signal above the noise in the photodetector and amplifier stages. This precludes their use as detectors of reflected radiation. In practice a strong light source is beamed directly at the detectors and interruption of this radiation produces a signal which is essentially binary in nature, rather than analog. (b) The resolution of an array for determining size is governed by the number and spacing of individual detectors. Since each detector requires its own circuit and a separate connection to a logic gate, the practical difficulties of mounting, spacing and interconnection limit the scan resolution of these systems.

Devices falling within the third group, using television camera tubes, usually use either a Vidicon or Plumbicon type of tube. The great advantage of using a television camera type of detector is that these detectors make use of the storage principle to produce useable signals from relatively low brightness image characteristics. This type of detector is therefore suitable for sorters operating on reflected light. In the storage principle the elements of a photosensitive surface are scanned by an electron beam once every scan interval. In between scans the local photon flux is integrated. It is this integration which provides the useable signal. The television camera system has several disadvantages and limitations which are indicated in the following material. (a) The persistence or lag caused by the time constant of the photoconductive process is a definite limitation. For example, in a typical Vidicon tube it may take 50 milliseconds for the photocurrent to decay to 20 % of its original value after illumination is removed. A modern sorting apparatus may handle pieces of rock travelling in excess of 1,000 ft/minute (5 milliseconds/inch). It is unacceptable to have the image of a rock still contributing to the signal being produced by the scan when the rock is in fact 10 inches downstream of the scan zone. (b) Non-linearity and noise are masked by phosphor characteristics and eye accommodation when the video signal is used to reproduce a display on a monitor, however, when the video signal is used as an input to a comparator in a sorting application, non-linearity and noise are significant sources of error. (c) Vidicon type image pick-up tubes are susceptible to light burn of the photoconductor, electron beam raster burn, thermionic cathode failure and vacuum leaks. Also, degradation occurs during what is normally a relatively short life.

SUMMARY OF THE INVENTION

It is an object of the present invention to reduce or overcome disadvantages in the three groups of sorting devices referred to above and to provide a novel sorting apparatus.

The present invention makes use of a closely spaced single line array of photodiodes operating in a photon flux integrating mode as a self scanning light detector. This allows low values of reflected light to be detected, with high resolution, and is consequently unlike the instantaneous value discrete photodiode systems mentioned above. The scan is electronic and not mechanical which makes it capable of very high scan rates. In addition noise is low, lag is negligible, the associated drive and logic is simple, and the response is linear with great dynamic range.

In the present invention, which uses multiple deflection channels, the photodetector scan timing, circuit is also used to synchronize the demultiplexing of the video data.

The present invention provides an apparatus for sorting in accordance with light reflected from a stream of objects moving through a sorting zone along a predetermined path having a predetermined width, comprising a single line array of photodiodes each having a photosensitive semiconductor junction and adapted for operation in a photon flux storage mode, illuminating means to direct source of light into said sorting zone across said predetermined width of said path, a lens system to focus an image of said stream extending across the illuminated width of said path onto said array, a plurality of deflection means in said sorting zone extending across the width of said path in side by side relationship, each deflection means defining a channel, switch means for connecting to a common output each photodiode singly and in succession through said array to provide at said common output a first signal representing a succession of values of reflected light impinging on each photodiode during a predetermined interval, timing means to cycle said switch means successive operations through said array and to provide timing signals relating portions of said first signal to respective channels, and control means responsive to said first signal and to said timing signals to cause actuation of respective deflection means to deflect objects which reflected light of predetermined characteristics.

BRIEF DESCRIPTION OF THE DRAWING

The single FIGURE is a drawing, partly in schematic block diagram form, showing the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the drawing there is shown a belt 10 passing over a head pulley 11. The belt 10 carries a stream of pieces of rock 12 distributed on it to form a limited width stream of rocks in a single layer. Only a portion of belt 10 is shown as it is well known in the art to have a sorting apparatus with a moving belt which carries a single layer of objects on it. One example of such a system is described in United States patent application No. 391,909 to Wilhelm Hieronymus, filed Aug. 27, 1973 and another in aforementioned U.S. Pat. No. 3,545,610. The pieces of rock 12 are discharged from the belt 10 in a trajectory which passes in front of a deflection device 14 which comprises a plurality of nozzles 15 each with a separate supply of fluid connected to it. The fluid is normally compressed air and this supply is indicated by arrows and letters *a-j* shown beneath deflection device 15. Such deflection devices are also well known and are described, for example in the aforementioned U.S. Pat. No. 3,545,610. The nozzles 15 may be considered as dividing the stream into multiple deflection channels.

A light source (not shown) illuminates the pieces of rock in the scanning zone. A lens system, indicated schematically at 16, focuses an image of the stream of rocks onto a scanning means 17. The broken lines 18 indicate this. The broken lines 18 indicate the scanning zone on belt 10.

The scanning means 17 may comprise a single line array and preferably a linear array of photodiodes 20 with the axis of the array being transverse to the flow

of stream of rocks. The photodiodes are preferably integrated into a single monolithic chip and may have a sensitive area of approximately 1 mil² and be spaced on 1 mil centres. Thus, a sensitive area of 0.5 inch × 0.001 inch would contain 500 photodiodes, and the corresponding image would have 500 elements. This is, if a 25 inch scan were used there would be 500 picture elements on the scanned area, each being 0.050 inch × 0.050 inch. Photodiodes arranged in monolithic chips of this nature are available on the market.

The scanning means 17 of photodiodes 20 has associated with it a corresponding array of switches 21 which are preferably FET type switches. The switches 21 serve to connect each photodiode 20 to a common video output line 22. That is, when an individual switch 21 is closed it connects the associated photodiode 20 to output line 22. A shift register 23 generates a sequence of signals or signal pulses which actuates each photodiode 20 singly and in turn. This provides the electronic scan. It is convenient to have the array of photodiodes 20, the switches 21 and the shift register 23 integrated on a single chip. Such an integrated device requires only power and output connections and a drive for the shift register. There are integrated devices of this type available on the market.

A simplified circuitry and apparatus for adapting a linear array of photodiodes, as described, to a sorting operation will now be described. The drive for shift register 23 may comprise a clock generator 24 for providing the clock pulses for operation, a presettable counter 25, and a start pulse generator 26. The counter 25 counts the clock pulses up to the number of photodiode elements in the array, then the counter 25 resets and provides a signal to the start pulse generator 26 causing it to generate a start pulse. The start pulse is applied to shift register 23 to initiate the shift register sequence, and the clock pulses from generator 24 are also applied to shift register 23 to cause operation of the shift register sequence once it is initiated.

The start pulses from pulse generator 26 is also applied to a divider/counter 27, and the clock pulses from clock generator 24 are also applied to the divider/counter 27. The divider 27 gives an output pulse after it receives a predetermined number of clock pulses. The predetermined number is chosen to correspond to the number of photodiodes which view a single one of the multiple channels. That is, the divider 27 provides one output pulse as the scan crosses each one of the multiple channels. This output pulse from divider 27 is applied to converter 28.

Converter 28 may not be required in some circuit arrangements as will be apparent to those skilled in the art. In a preferred form converter 28 is a form of counter which counts the pulses representing the passage of a scan across each channel and produces a binary coded digital signal representing the number on parallel output lines. The output of counter 28 or converter 28 is applied to demultiplexer 30 which decodes the binary information to sequentially gate open individual channels. A signal representing video information is also applied to demultiplexer 30 over conductor 31. Thus, the demultiplexer 30 serves to switch the incoming signal representing the video information to the outputs, indicated as *a-j*, in sequence, so that the video information representing the scan in the first channel or the "*a*" channel goes to the output "*a*" of

the demultiplexer. Circuitry for demultiplexing in this manner is well known.

As was previously mentioned, the video or scan information is available on the conductor or common video output line 22, and this is in the form of pulses of varying amplitude. A circuit represented by a power supply 33 and a resistance 34 is connected to line 32. Each photodiode is reverse biased by power supply 33 through resistance 34 and line 22 as its respective one of switches 22 is turned "on" and is then open circuited for the remainder of the scan period when the switch is "off" or in the high resistance state. If light falls on the photodiode during the time when the switch is in its off condition or open circuited, a photo-generated current discharges the junction capacitance and the amount of charge removed is proportional to the total incident illumination in that interval of time. When the switch is momentarily switched to its on condition, the photodiode is recharged through resistance 34 and line 22. The charging current pulse appears across load resistance 34 as a pulse of video information. Thus the video information which consists of a repeated sequence of these pulses, is applied to amplifier 32. The amplified video signal may be passed through a video processor 35 to conductor 31 and the demultiplexer 30. The video processor 35 may convert the basic analog video data to binary form if this is required in subsequent stages. The video processor 35 may include transient blanking gates to eliminate any transients which appear as a result of the switching. The video processor may include automatic gain control circuitry, or it may include any other desired circuitry.

The output from the demultiplexer 30 appears on individual channel circuits as indicated in the drawing as $a - j$. The individual channel circuits are identical and only one (associated with channel a) will be described. The video output for channel a is applied to a decision and timing circuit 36. This circuit compares the video signal it receives in some manner to a predetermined or derived reference or references and provides an output if deflection is to take place. The decision and timing circuit may be of the type described in the aforementioned U.S. Pat. No. 3,545,610 although other types may be used. The output from decision and timing circuit 36 is applied to a deflection control device 37 which normally includes a valve to open and close between a supply of fluid under pressure and the nozzle 15 at a in the deflection device 15.

It is a feature of the present invention that a single master oscillator or clock pulse generator 24 is used to synchronize both the scanning means and the demultiplexer. This simplifies the apparatus while maintaining a high degree of precision. For example, the frequency of operation of clock pulse generator 24 may be adjusted to meet various requirements without affecting the precision. The signal for each photodiode remains locked to the correct channel. If the clock frequency is reduced, a lower scan frequency will result with a proportional increase in video signal for a given light level. This is because of the integrating ability of the photodiode in the present arrangement. However the reduced frequency does not result in any adjustment or synchronization problems. In addition, it is a relatively simple matter to change the number of photodiodes representing a channel, or the number of channels per scan, as may be required for a particular sorter configuration.

The linearity of the scan division is precise. This precision derives from two features which provide improved results over an electron beam type of scan or a mechanical scan. First, since a plane surface (the stream of objects on a belt) is being imaged onto a line of photodiodes in a flat plane, equal divisions at the object plane appear as equal divisions on the image plane, regardless of position with respect to the axis of the lens system. Thus, the resolution does not vary from one part of the scan to another. Second, the clock generator is used both as a timer and a switching control. While the timing is important, the locking together of the scanner switching and the demultiplexing by a direct count rather than by time contributes to the accuracy of the scan. This count/scan position relationship results in much simpler channel gating and video processing as compared to an electron beam scan (Vidicon type) or a mechanical scan. Both the electron beam scan and the mechanical scan use time as a basis for scan position and channel division and linearity is frequently a problem.

I claim:

1. Apparatus for sorting in accordance with light reflected from a stream of objects moving through a sorting zone along a predetermined path having a predetermined width, comprising
 - a single line array comprising a plurality of photodiodes integrated into a single monolithic chip, each having a photosensitive semiconductor junction and adapted for operation in a photon flux storage mode,
 - illuminating means to direct a source of light into said sorting zone across said predetermined width of said path,
 - a lens system to focus an image of said stream extending across the illuminated width of said path onto said array,
 - a plurality of deflection means in said sorting zone extending across the width of said path in side by side relationship, each deflection means defining a channel, the number of photodiodes being of an order of magnitude greater than the number of channels,
 - switch means compressing a semiconductor switch for each photodiode for connecting to a common output each photodiode singly and in succession through said array to provide at said common output a first signal representing a succession of values of reflected light impinging on each photodiode during a predetermined interval,
 - timing means comprising a shift register having a unit for each said semiconductor switch, a source of clock pulses to step said shift register through successive cycles to actuate said semiconductor switches in sequence, and a counter to count a predetermined number of clock pulses corresponding to a channel and to provide a timing signal for each count relating portions of said first signal to respective channels, and
 - control means including a demultiplexer having a section for each channel, each section being connected for actuation of a respective deflection means, said sections being enabled in sequence by said timing signal from said counter, and a signal treating means for processing said first signal and applying the processed signal to said demultiplexer for actuating enabled deflection means for the deflection of objects which reflected light of predetermined characteristics.

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