United States Patent

McMahon et al.

[15] **3,638,232**

[45] **Jan. 25, 1972**

[54] REAL-TIME COHERENT OPTICAL PROCESSOR

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[73] Assignee: **Sperry Rand Corporation**

[22] Filed: **Jan. 23, 1970**

[21] Appl. No.: **5,437**

[52] **U.S. Cl.** .....**346/74 CR**, 178/6.6 A, 355/5

[51] **Int. Cl.**.....**G03g 15/04**, G01d 15/06

[58] **Field of Search**.....346/74 CR, 74 P, 74 ES; 178/6.6 A, 7.5 D, 7.3 D; 355/5

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[57] **ABSTRACT**

A coherent optical processor comprising writing, developing, readout and erasing stations disposed proximate to and consecutively spaced along the direction of motion of a rotatable drum having a photoconductive layer affixed thereto. A time-varying signal is written on the photoconductive layer by first establishing a uniform electrostatic charge thereon and then applying a light beam to spatially modulate the electrostatic charge pattern in accordance with time-amplitude variations of the light beam. Next it is exposed to a cloud of toner particles at the developing station whereat the spatially distributed electrostatic charge pattern is converted to a visible image of varying transparency. Optical processing is performed as the visible image passes the readout station where it intersects a laser beam and thereafter the toner image is erased from the tape in readiness for the next cycle of operation commencing at the writing station.

4 Claims, 3 Drawing Figures

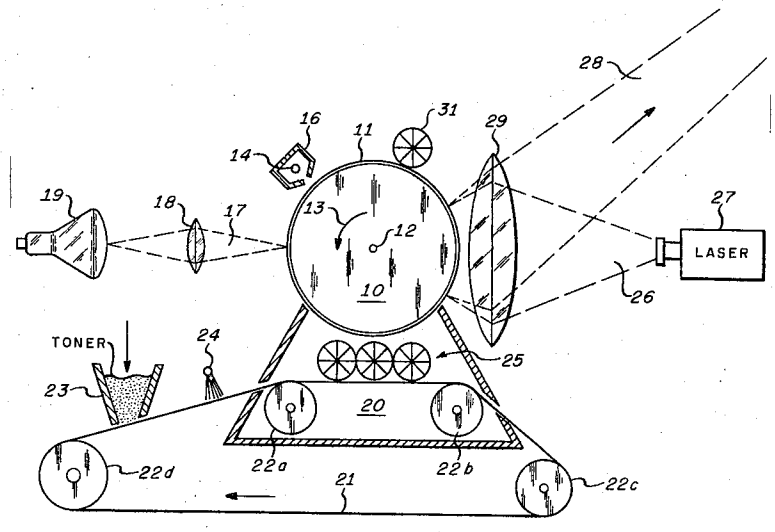
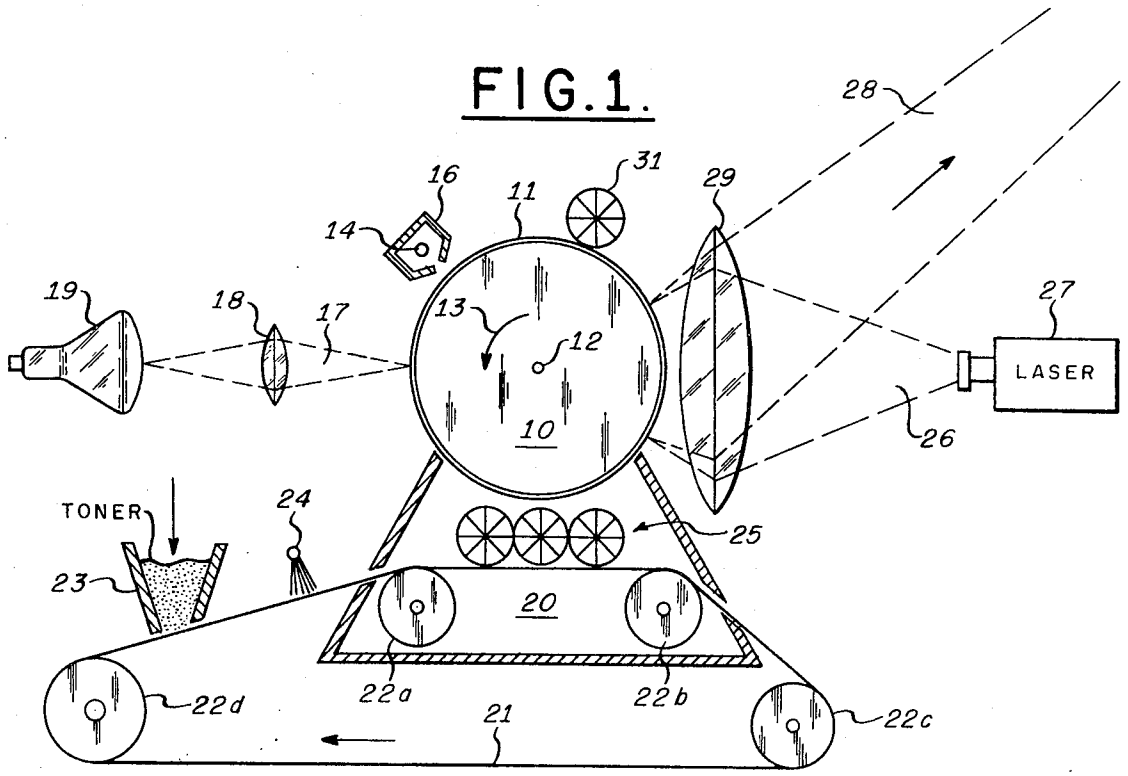


FIG. 1.



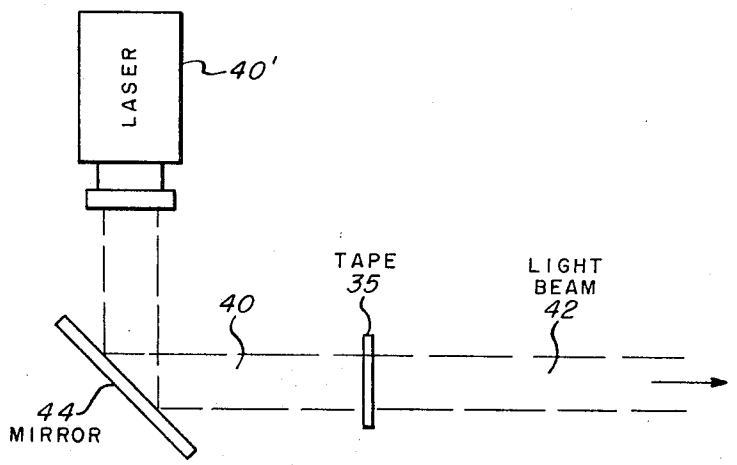


FIG. 3.

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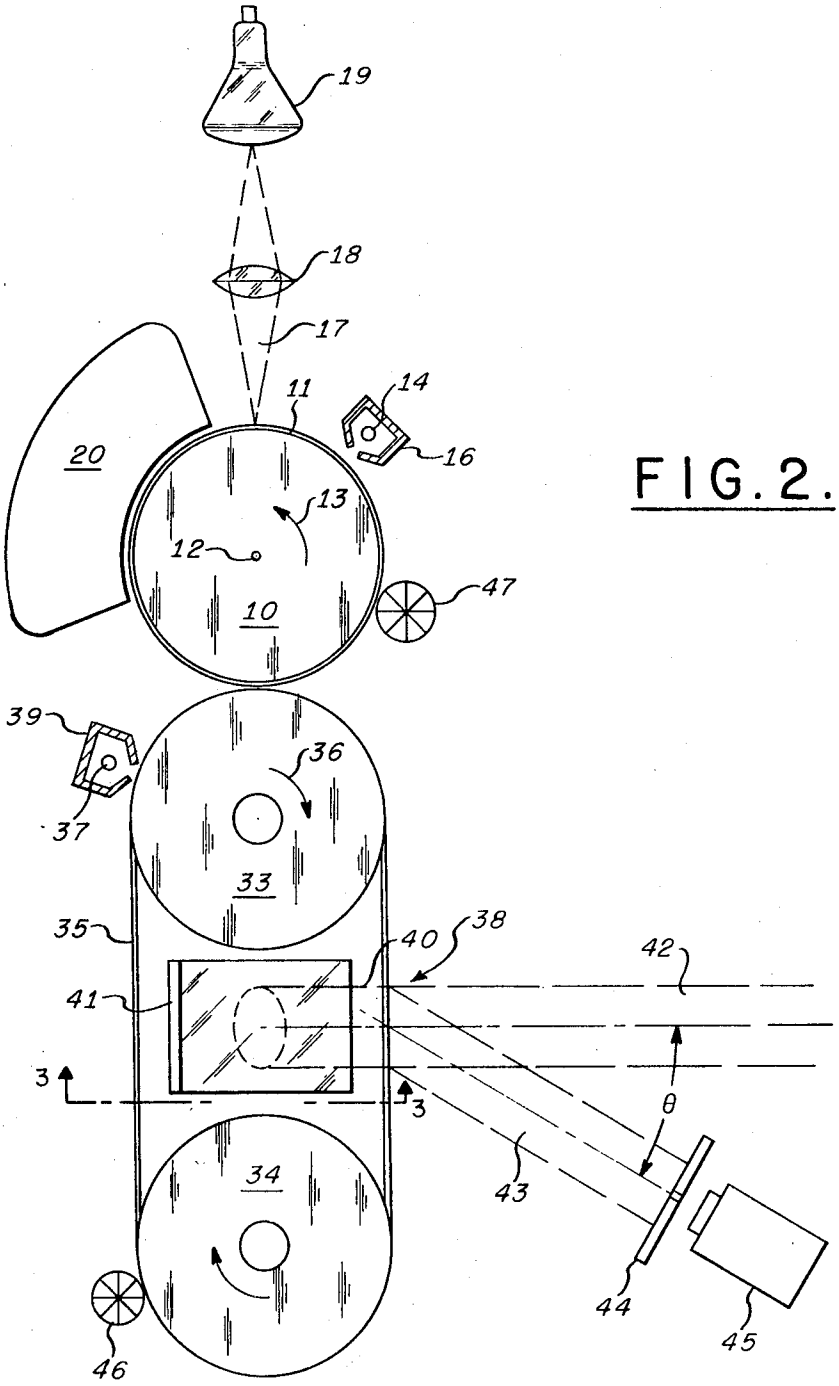


FIG. 2.

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REAL-TIME COHERENT OPTICAL PROCESSOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to optical processors and more particularly to a coherent optical processor utilizing electrophotographic techniques and having the capability of operating substantially in real-time with maximum processing delays of about 1 second or less.

2. Description of the Prior Art

A coherent optical processor typically includes a transparency on which the signal to be processed is recorded in the form of a two-dimensional pattern of varying opacity or thickness for respectively affecting the intensity or phase of a coherent light beam propagated therethrough, the recording transparency being used in conjunction with additional components such as lenses and spatial filters for performing correlation, pulse compression, spectrum analysis and other functions as is well known to those skilled in the art.

In the early state of the art photographic film was generally used as the recording means because of its many excellent properties, particularly regarding resolution and sensitivity. Photographic film has the disadvantage, however, of not being reusable and further requires considerable development time which precludes its applicability to real-time (instantaneous) signal-processing operation. In the interest of overcoming these limitations other recording medial have been investigated in recent years. Ultrasonic delay lines and photochromic materials in particular have received considerable attention. Both of these devices are capable of operating in real-time but each has inherent limitations. Ultrasonic delay lines, for example, are not suitable for processing signals having a time duration larger than the time required for an acoustic wave to propagate from one end of the line to the other, usually less than 100 microseconds. Photochromic materials, on the other hand, have the disadvantage compared to other materials of being extremely insensitive to light, particularly in the erasure mode, to the extent that development of a practical device has thus far been precluded.

Other materials such as ferroelectrics and arrays of electro-optic and liquid crystals have also been investigated but research in these areas is in the formative stages and therefore it is not known whether the desired characteristics of reversibility (for repetitive writing and erasing), high sensitivity (for fast writing), minimum delay time (for real-time processing), large storage capacity (for high resolution), stability and non-destructive readout will be realized with such materials. These characteristics are attainable, however, at the present time with a coherent optical processor constructed in accordance with the electrophotographic technique of the present invention as will become apparent from the subsequent detailed description of the preferred embodiment.

SUMMARY OF THE INVENTION

In a preferred embodiment of the present invention a signal which is to be processed is temporarily recorded on a photoconductive medium affixed to a rotatable drum in preparation for presentation in the path of a light beam emitted from a laser source constituting a part of the processor. Various means are positioned adjacent the drum in spaced relation therealong for performing a complete operating cycle including precharge, write, develop, process and erase stages which are accomplished in succession as a given region of the drum moves past discrete stations whereat the respective means are located. More specifically, at the inception of an operating cycle a precharging electrode establishes a substantially uniform electrostatic charge of predetermined polarity on a given region of the photoconductive medium and thereafter the signal to be processed is written thereon by means of an optical signal incident on the drum. As the uniformly charged region of the photoconductive medium moves past the optical writing station the charge pattern is spatially modulated in accordance with the time variations of the optical signal. Next, the spatially modulated electrostatic charge pattern is converted to a corresponding visual pattern of varying transparency by exposing the photoconductive medium at a developing station to toner particles which are attracted to the electrostatically charged segments of the photoconductive medium in proportion to the charge existing thereon. The resulting visual signal pattern is then moved across the propagational path of a coherent light beam emitted from a laser source whereupon the optical processing is performed in conjunction with other conventional components referred to hereinbefore. As the concluding step of an operating cycle the toner is brushed away from the tape at an erasure station preparatory to the beginning of the next cycle.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified schematic plan view of one embodiment of the invention.

FIG. 2 is a simplified schematic plan view of another embodiment of the invention.

FIG. 3 is a view taken along line 3—3 showing the laser source position relative to the embodiment of FIG. 2.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, aluminum drum **10** has a photoconductive layer **11**, typically selenium, affixed thereto and is rotated counterclockwise about axis **12** in the direction of arrow **13** by a motor not shown in the drawing. In operation of the processor, as the drum rotates past corona charging wire **14**, which extends transverse to the plane of the drawing in conductive housing **16**, the adjacent region of the selenium is uniformly electrostatically charged to a potential of approximately 700 volts. This is successfully accomplished by energizing the charging wire from a +5,000 to +7,500 volts DC source. Thereafter, signal information is written on the drum by intensity modulating an optical beam **17** focused on the selenium by means of lens **18** which enhances the writing resolution. The optical writing beam may be obtained, for example, from the display screen of a cathode-ray tube **19** such that successive line scans of the cathode-ray beam in a direction perpendicular to the plane of the drawing produces similar line scans on the drum, each scan being across a discrete portion of the selenium as a consequence of the rotation of the drum. The optical writing beam has the effect of discharging the selenium by photoconduction at those points where it is illuminated while leaving it fully charged at the unexposed points. As a result of this action an electrostatic charge image is recorded on the drum in correspondence to the applied optical writing signal, that is, the time-varying intensity modulating optical signal is recorded as a spatially varying electrostatic charge pattern.

Upon rotating to the location of developing station **20** the spatially distributed charge pattern is converted to an identical visual pattern by applying toner (minute particles of carbon impregnated in resin or plastic) to the drum. This can be accomplished by any of various techniques well known in the art as, for example, by establishing in the vicinity of the drum periphery a cloud of toner particles having a charge opposite to the charge on the selenium. Preferably, toner particles which tend to acquire a negative triboelectric charge are used and, if desired, additional negative charge may be imparted to the toner so that it readily adheres to the positively charged segments of the drum in proportion to the charge existing thereon while the uncharged segments, namely, the segments completely discharged by the optical writing beam, remain substantially devoid of toner particles. Hence, gray scale recording is possible inasmuch as segments having an intermediate charge level capture some toner but less than segments which are highly charged. An illustrative apparatus for performing the developing function comprises a canvas belt **21** which moves in a clockwise direction on discs **22***a*, **22***b*, **22***c* and **22***d*. Toner is applied to the belt from a hopper **23**. Before entering the developing station a negative charge is

established on the toner by carrying it past a wire brush **24** in gentle contact therewith. In the developing station brushes **25** constructed of an insulating material brush the toner away from the canvas belt so as to form a cloud of negatively charged toner particles which are attracted to the charged regions of the selenium as explained above. It should be noted that an image which is a negative of that produced by the foregoing procedure could be formed simply by selecting the writing potential and toner particle polarities to achieve such result.

After leaving the developing location and rotating slightly further in the counterclockwise direction the visual pattern recorded on the drum intercepts light beam **26** emitted from laser source **27** whereupon diffracted beam **28** is produced by virtue of reflection from the developed toner image pattern recorded on the drum. Cylindrical lens **29** slightly focuses both the incident and reflective light, thereby compensating for the cylindrical shape of the drum surface and further segregating undiffracted light from the diffracted light which is representative of the signal information on the drum. Various optical processing systems can be implemented with this setup. For instance, correlation can be performed by placing a reference pattern such as a film transparency in the path of the reflected beam, or if desired, in the path of the incident beam on either side of lens **29**. Alternatively, the correlation can be performed by means of a modulated light beam used in lieu of a reference transparency as is known to those skilled in the art; or, if required, the modulated light source can be used in conjunction with the reference transparency. In any event, it should be understood that a laser is not necessarily required as the light source. In many instances it is merely required that the light source be spatially coherent to such an extent that at any instant the phase at any point along one ray of the beam can be determined with reference to points along the other rays of the beam. In some cases, though, temporal coherence is required so that the phase at one instant can be ascertained with reference to that at another instant.

One example of an application requiring a temporally coherent source is a television system for transmitting three-dimensional holographic data. A system of this type can be implemented by scanning a holographic pattern with a needlepoint light beam and applying the signal obtained therefrom to the Z axis of cathode-ray tube **19** for the purpose of intensity modulating the scanning light spot appearing on its screen whereby the holographic interference pattern is recorded on the selenium drum. Upon reaching the readout position where the visual pattern is illuminated by the laser, the reflected diffracted light presents a reconstructed wave front which forms a virtual image of the original holographically recorded object, the temporal coherence of the laser being sufficient to present the full depth of the image without distortion.

As the drum rotates further in the direction of arrow **13** the recorded visual pattern leaves the optical processing or readout location and arrives at an erasure station where brush **31** removes the toner in cooperation with a vacuum system (not shown) and thus erases the visual image in preparation for uniform charging by corona charging wire **14** at the beginning of the next cycle of operation. To facilitate the removal of this toner image, the erasure station can also include sources of illumination and/or corona discharge devices positioned between successive brushes or sets of brushes disposed along the direction of drum rotation to regulate the charge remaining on the drum. Although most signal-processing operations will be performed with the entire recording pattern instantaneously appearing in the path of laser beam **26**, it will be appreciated that this is not an absolute limitation on the time duration of the signal to be processed since the various stages of the cycle could be performed with the full circumferential length of the drum being utilized. A system of the foregoing nature, however, does require a drum precisely machined to optical tolerances for exact concentric rotation about its center axis. In addition, precision cylindrical lenses are required to correct for optical field curvature produced by the curvature of the drum. These requirements can be erased to some extent by utilizing a very small section of the drum surface for recording the signal information. Nevertheless, in many instances it will be necessary or at least preferable to circumvent these undesirable features of the drum configuration by utilizing the drum in conjunction with a continuous loop tape as shown in FIG. **2** wherein identical components have the same numeral designations.

In this arrangement, after precharging, optical writing and developing as explained with reference to FIG. **1**, the visual image is contact transferred to transparent tape **35**, which would on aluminum discs **33** and **34**, simply by moving the tape clockwise, as indicated by arrow **36**, in contact with the counterclockwise rotating drum **10**. To enhance the image transfer the tape is first charged to a potential of approximately +1,000 volts by corona charging wire **37** held at a potential of +5,000 volts within conductive housing **39**. Transparent plastic tape of high optical quality has been found suitable for operation in this manner. It should be understood that the above-mentioned voltage and other voltages previously mentioned herein are intended to be illustrative only, different voltages being suitable depending on the location and spacing of the various components.

After the drum image has been transferred to the tape it is carried to a readout station **38** where it traverses a light beam **40** directed thereon from a laser **40'** by way of mirror **41** canted 45° to the plane of the drawing as is more clearly shown in FIG. **3**. Optical processing is then performed in the manner described with reference to FIG. **1**, the undiffracted beam **42** being angularly displaced from the diffracted beam **43** by an angle θ as indicated in the drawing. Another use of the processor, in addition to the correlation and three-dimensional display applications previously mentioned, is indicated by the movable slit **44** used in combination with photodetector **45** for the purpose of performing spectrum analysis. Various wavelengths in a given diffraction order are selected simply by moving the slit in the direction of angle θ along the plane of the drawing.

At the completion of the optical processing the toner image is erased from the tape by brush **46** in readiness for recycling in contact with the selenium drum. In a similar manner, any toner remaining on the drum after contact with the tape is removed by brush **47**.

While the invention has been described in its preferred embodiments, it is to be understood that the words which have been used are words of description rather than limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention in its broader aspects.

We claim:

1. A coherent optical correlator comprising,

recording means,

means for writing a signal on said recording means in the form of a spatially distributed electrostatic charge pattern varying in accordance with time-amplitude variations of said writing signal,

means for developing the electrostatic charge pattern written on said recording means to convert said charge pattern to a corresponding visual image representative of said writing signal,

means including a light source for providing a spatially coherent light beam directed onto said developed visual image,

light focusing means positioned to receive the spatially coherent light beam subsequent to impinging on said visual image for separating diffracted and undiffracted components of the beam, and

means for erasing the signal pattern on said recording means after irradiation thereof by said spatially coherent beam.

2. The apparatus of claim **1** wherein said writing means includes precharging means for initially establishing a substan-

tially uniform electrostatic charge in a given region of said recording means in preparation for modulation by said writing signal.

3. The apparatus of claim 2 wherein said recording means comprises a photoconductive material, said writing means includes means for directing a writing light beam onto said photoconductive material subsequent to precharging thereof for altering the electrostatic charge at discrete points in said given region to form the electrostatic charge pattern thereon in accordance with the time-amplitude variations of said writing light beam, and said developing means includes means for applying to said recording means toner particles having a charge opposite to that of the electrostatic precharge whereby the particles adhere to discrete points on the recording means in accordance with the electrostatic charge thereat.

4. A coherent optical correlator comprising

a rotatable conductive drum having a photoconductive layer formed on the cylindrical periphery thereof,

precharging means positioned adjacent said drum for establishing a substantially uniform electrostatic charge in a given region of the photoconductive layer as the drum moves past said precharging means,

writing means spaced from said precharging means in the direction of motion of said drum for varying the electrostatic charge at discrete points in said given region to form an electrostatic charge pattern therein in accordance with time-amplitude variations of a writing signal,

developing means spaced from said writing means in the direction of motion of said recording medium for converting the electrostatic charge pattern formed on said recording medium to a corresponding visual image representative of said writing signal,

a transparent belt in movable contacting relation with said rotatable drum,

means for charging a predetermined area of said belt with a charge polarity opposite to that of the electrostatic charge pattern to effect the contacting transfer of said visual image from the drum to the belt,

light source means for directing a spatially coherent light beam onto said predetermined area of the belt as the transferred visual image moves transverse to the propagational path of said coherent light beam,

light-focusing means positioned to receive the spatially coherent light beam transmitted through the belt for separating diffracted and undiffracted components of the beam,

means spaced from the intersection of said coherent light beam with said belt in the direction of motion thereof for erasing said visual image, and

means for erasing any visual image remaining on the drum after image transfer to the belt.

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