Automatic-Exposure Control for a High-Resolution Camera

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Photography of distant objects requires accurate exposure to achieve maximum contrast with high-contrast emulsions. The autoexposure unit described in this paper has been designed for the ROTI Mark II tracking instrument to provide the necessary control. A pair of graduated neutral density disks is used to vary the light level at the film plane. By maintaining full aperture, maximum resolution is achieved for all light conditions.

The ROTI Mark II telescope system was designed to photograph missiles at extreme slant ranges. Maximum optical resolution was desired and therefore a telescope was designed with a 24-in. aperture and focal lengths of 100 to 500 in. The telescope has a highly corrected optical system with a laboratory resolution of $\frac{1}{3}$ sec of arc (theoretical limits of resolution are $\frac{1}{5}$ sec). A 25-ft tower supports the ROTI telescope on its roof to minimize the effects of ground level atmospheric disturbances (Fig. 1). Radar-controlled focusing adjusts for target range variations.

At long slant ranges, atmospheric attenuation results in low contrast between the object and background. For recording the maximum of information, it is necessary to use high-contrast emulsions and high-contrast developing. Increases in image contrast are limited by corresponding decreases in exposure latitude; therefore an automatic exposure control system was included in the ROTI Mark II tracking instrument. The autoexposure unit maintains a constant average light level at the film plane of the 70mm Photosonics motion-picture camera as the target crosses backgrounds of varying brightness.

Exposure Controls

Three methods of controlling exposure were investigated. A method utilizing variable-density polarizers was considered. It was rejected because absorption through the polarizers would have greatly decreased the light transmission of the system.

A second method considered involved the use of a variable iris, but the diffraction effects of the stop would have deteriorated the resolving power of the system. Resolution limits are a direct function of the focal length and aperture, and it would have been possible to reduce the iris by only one stop before the system resolution dropped below tolerable limits.

The method selected was to decrease evenly the transmission of the system across the entire aperture with a variable, neutral-density filter. Opposed disks with linear density coatings were designed to provide an equivalent 5-stop variation while maintaining even illumination across the field.

The disks were made of optical glass coated with Inconel and the density was a linear function of angular rotation of the disks within $\pm\frac{1}{8}$ stop, or about $\pm 10\%$ transmission. For coating, a wheel with variable width slots was rotated between the disks and an evaporating filament. The Inconel particles flowed to the glass through the slots which were adjusted to yield a gradient density which would give the proper slope to the transmission curve.

General Operation

The ROTI Mark II autoexposure unit was designed to maintain a constant level of illumination at the film plane with $\pm\frac{1}{4}$ stop accuracy. Ambient light within 32:1 range could be accommodated by a single setting.

In order to minimize manual adjustments to compensate for changes of focal lengths and color filters, samples of entering light are monitored by a detector. Ultimately the detector and associated servo system adjust the position of the variable-density disks. The level of illumination is sampled by four pick-off mirrors at the edge of the cone of light which converges at the camera aperture. These mirrors divert a portion of the light to the measuring portion of the system. The sampled light is proportional to the light reaching the film plane. Figure 2 is a block diagram of the autoexposure unit.

The measuring unit operates on a null principle alternately comparing a reference light with the entering light. The reference lamp operates from a 28-v source. The chopper operating at 1800 rpm is a transparent plastic disk with four alternate clear and reflecting quadrants. The clear sectors transmit while the aluminized sectors alternately reflect the reference light to the 1276 photomultiplier. The light projected in the photomultiplier becomes a 60-cycles/sec modulated signal and the amplitude of the signal is determined by the difference in intensity between the two light beams (Fig. 3).

The reference light is separately monitored. A beam splitter reflects a portion of the reference light to a selenium photocell and indicating micrometer. A rheo-

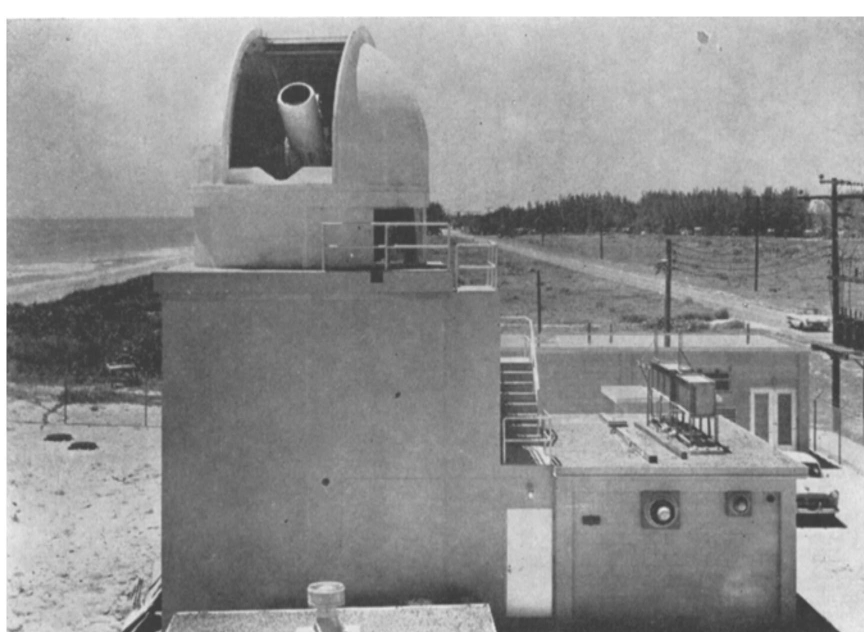

Fig. 1. ROTI Mark II installation.

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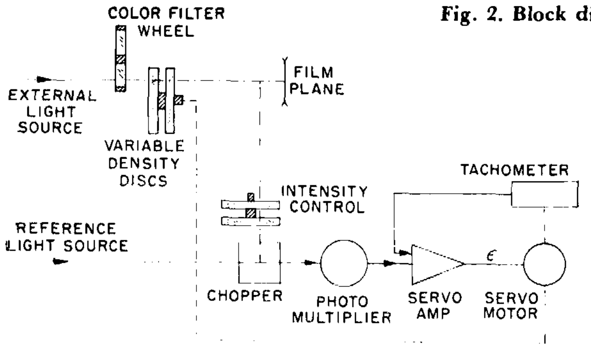

Fig. 2. Block diagram of the autoexposure unit.

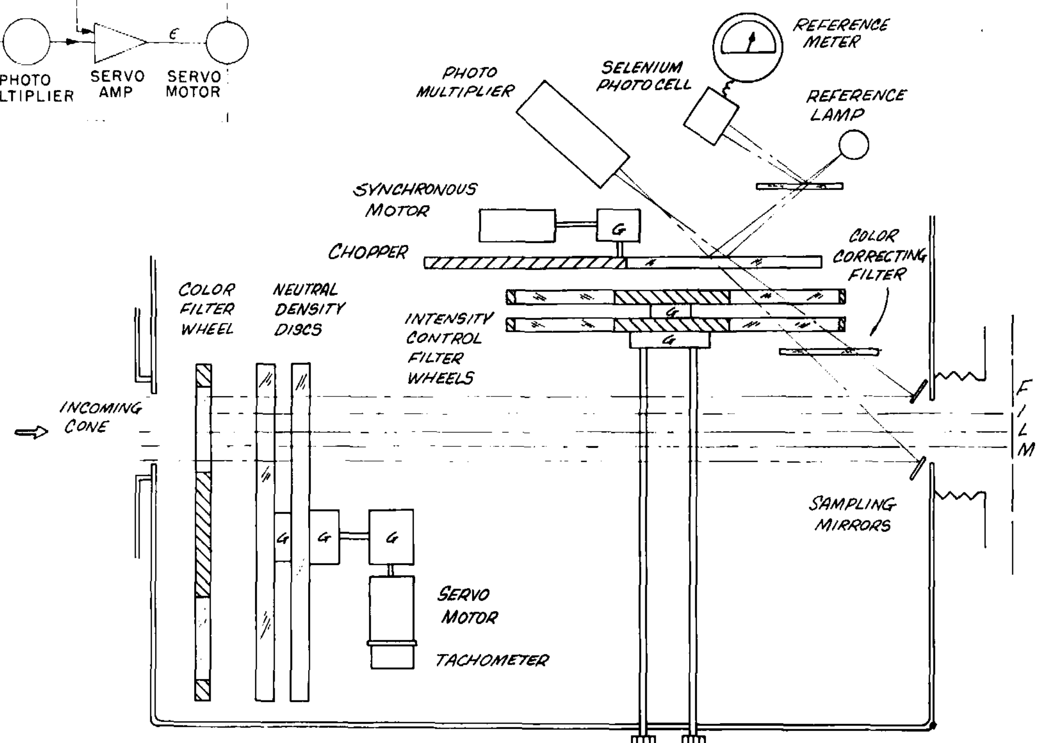

Fig. 3. Optical schematic of the autoexposure unit.

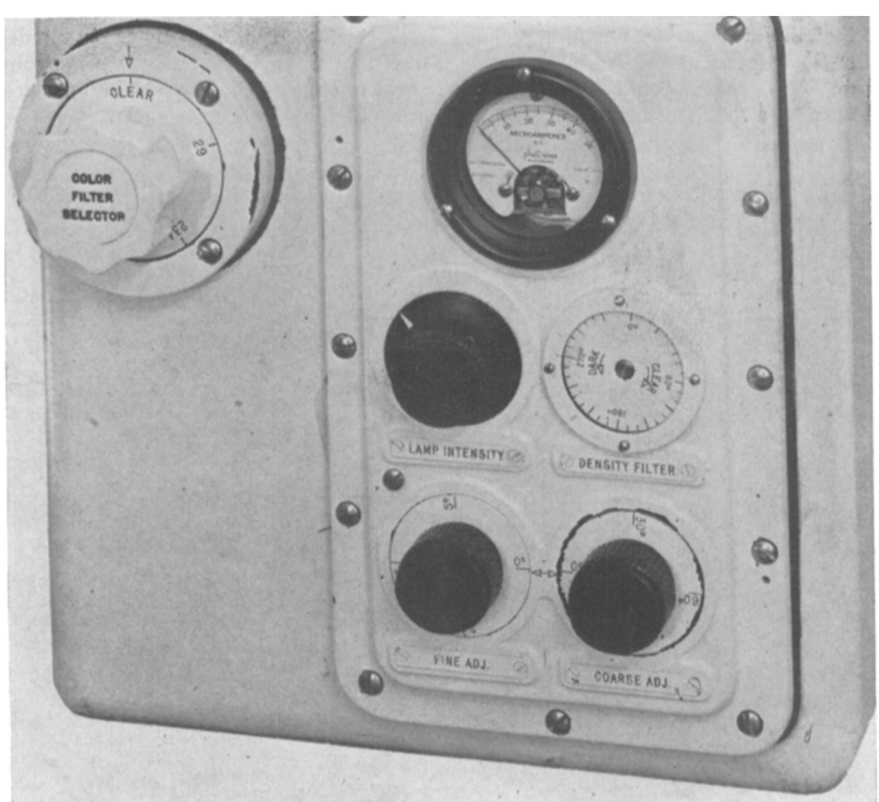

Fig. 4. The autoexposure main control panel.

stat controls this light intensity by varying the voltage to the lamp (Fig. 4).

The S-10 cathode of the photomultiplier does not have the same spectral sensitivity as the film emulsion; therefore, the light from the sampling mirrors is transmitted through a color-correcting filter which matches the sensitivity of the detector to the spectral sensitivity of Kodak Linagraph Shellburst film which is the standard emulsion intended for use in the ROTI Mark II instrument. The filter can readily be changed when film types are changed. Figure 5 is a photograph of the autoexposure unit in its housing.

The detector output voltage is a function of the energy level and wavelength of light; similarly the film density also varies depending on the energy level and wavelength.

The sensitivity set at the autoexposure unit with white light and no filter is defined as 100% response. With a filter in the light path, the spectrum of the light reaching the film and the detector is narrowed and the detector output will not exactly match the response of the film. Table I lists the accuracy of the color corrections when various filters are used, and gives the detector output relative to the film response.

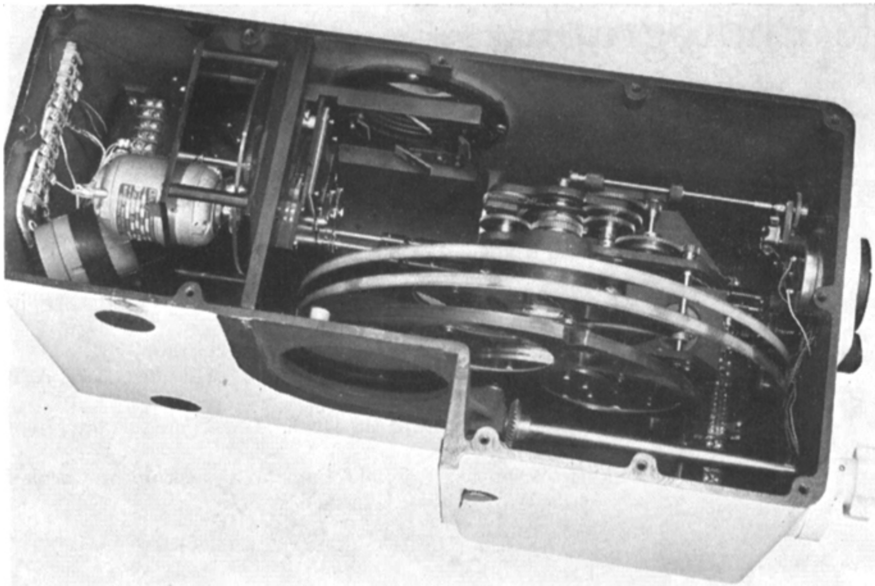

Fig. 5. Arrangement of components in autoexposure housing.

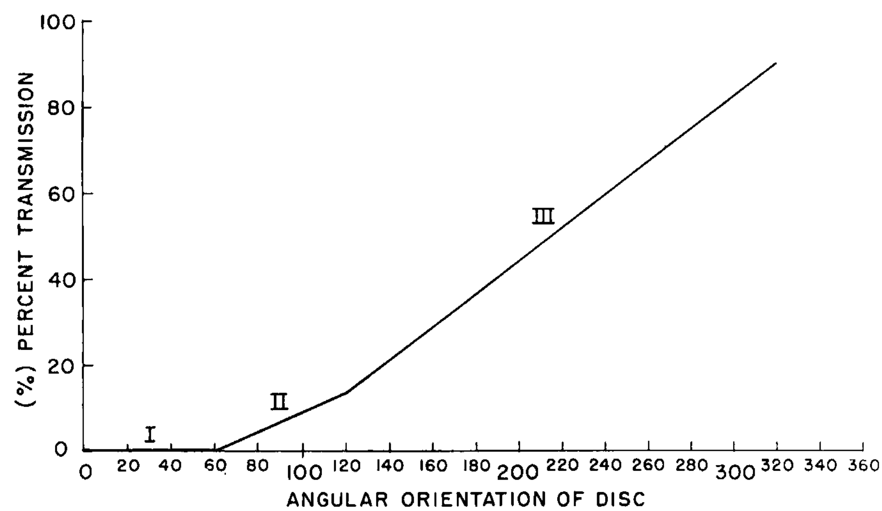

Fig. 6. Variable-density disk transmission curve.

Since the system is designed for use with the 70mm Photosonics camera with shutter openings that vary from 2° to 120° and frame rates of 10 to 60 per sec, the light level at the film plane could vary by a factor of 360. To accommodate these variations of intensity and to allow for the use of films of different speed, a pair of intensity control filter wheels also intercept the light from the telescope objective before it reaches the chopper and photomultiplier. The transmission of these filters ranges in steps of 1.59. Thus the intensity control filters adjust the light level at the film plane over the range of 0.1 to 100 lm per sq m.

The error signal is a voltage which is fed to a servo amplifier where it is amplified to drive a servomotor. The servomotor, in turn, drives the neutral density disks in a direction which reduces the error and tends to make the modified light from the sampling mirrors equal in intensity to the reference light.

The 14-in. diameter neutral density disks transmit from 3% to 100% of the peak transmission of the light entering the telescope objective. In order to maintain a constant light level within the $\pm\frac{1}{4}$ stop accuracy required, a pair of contra-rotating neutral density disks are used. The contra-rotation of the disks in one direction increases the density on each disk, and the transmission through the two is uniform when they are superimposed.

Table I

Telescope filter	Cutoff, millimicrons	Detector sensitivity (white light = 100)
Clear	—	100
8	480	99.1
15	528	88.3
23A	570	94.9
29	610	104.3

Out-of-focus ghost images from the variable-density disks caused some concern. These images occur from internal reflections between the disks, particularly in the high-density regions. Inconel was selected and only 140° of the second disk was coated to reduce the ghost images. The intensity of the ghost imagery is thus limited to a maximum of 2%.

Since the second disk was only partially used both disks had to be designed so that the density curves had three slopes rather than two. The shape of the curve was selected to minimize abruptness of the transition from the clear to the dense portions of the disks within the $\frac{1}{8}$-stop accuracy required. Each has a clear sector, a density coating to give a half-slope sector and another density coating to give a full-slope sector. These sectors are shown as I, II and III in the curve of density vs. angle (Fig. 6).

In operation, a clutch stops the second disk at the beginning of sector III, while the first disk is free to rotate to the higher density portion.

Conclusion

The use of variable-density coated optical glass disks in a null-type system with a reference light results in a stable autoexposure unit without noticeable loss in resolution or contrast. The autoexposure unit with the associated sampling mirrors maintains the illumination at the film plane within ±20% for changes of focal length from 100 to 500 in., and for selection of a wide range of filters and exposure times.