United States Patent

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Continuation-in-part of application Ser. No. 552,795, May 25, 1966.

[54] **AUTOMATIC FOCUSING MEANS USING AN ANALOG SIGNAL CORRELATOR**
6 Claims, 4 Drawing Figs.

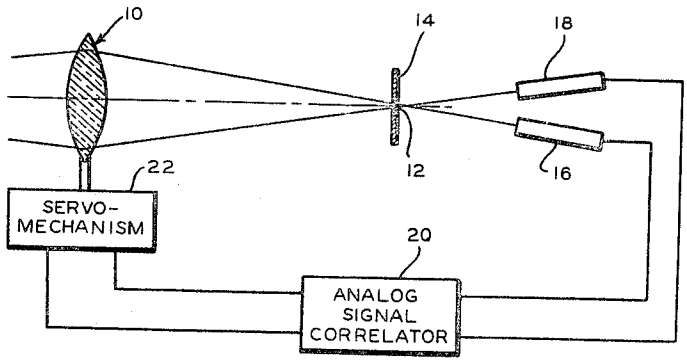
[52] **U.S. Cl.** **250/204,** 95/44, 356/123
[51] **Int. Cl.** **G01j 1/36,** G03b 3/00
[50] **Field of Search** 250/204; 95/44; 356/121; 355/123

[56] **References Cited**
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3,413,850	12/1968	Merrifield	250/204
3,450,883	6/1969	Thomas	250/204

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ABSTRACT: Apparatus for automatically focusing an optical device including means responsive to selected rays of an optical image being viewed, said means producing output responses representative of the selected rays being observed including variations therein, means for correlating the output signals to produce a correlation output, and means for focusing the optical device including means responsive to the correlation output.



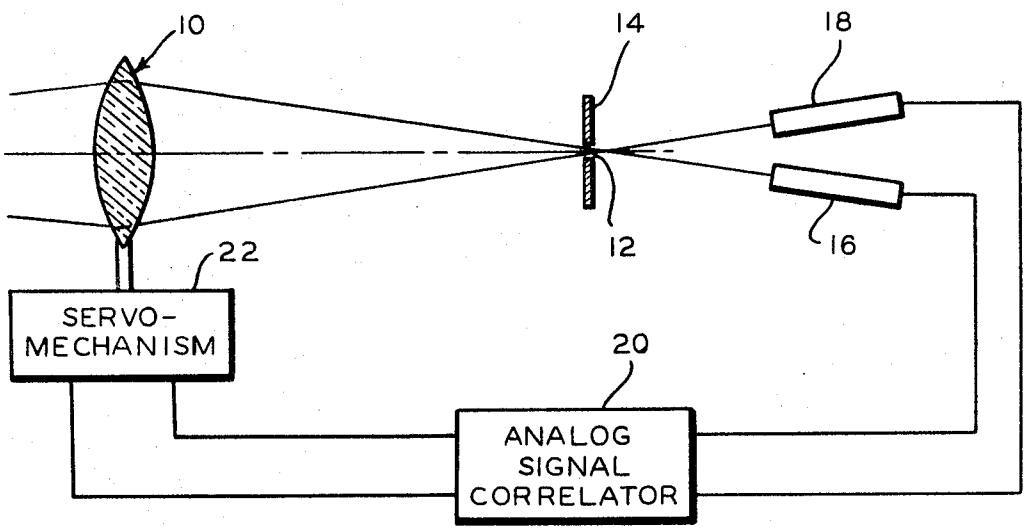


FIG. 1.

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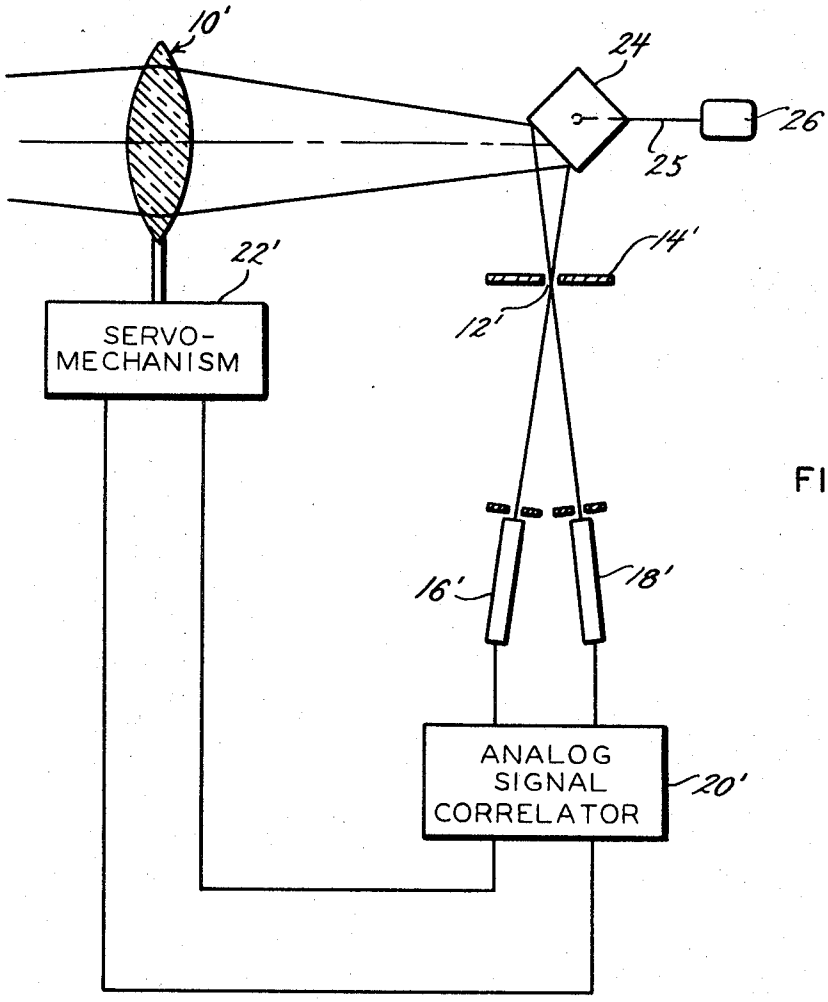


FIG. 2.

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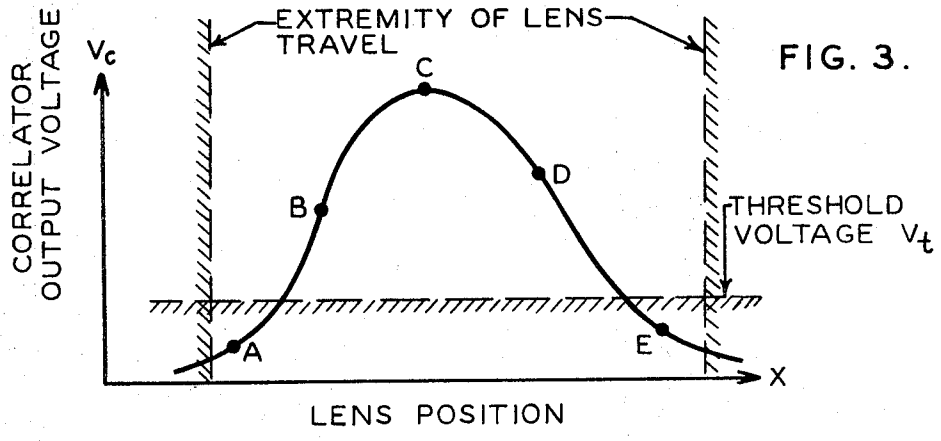


FIG. 3.

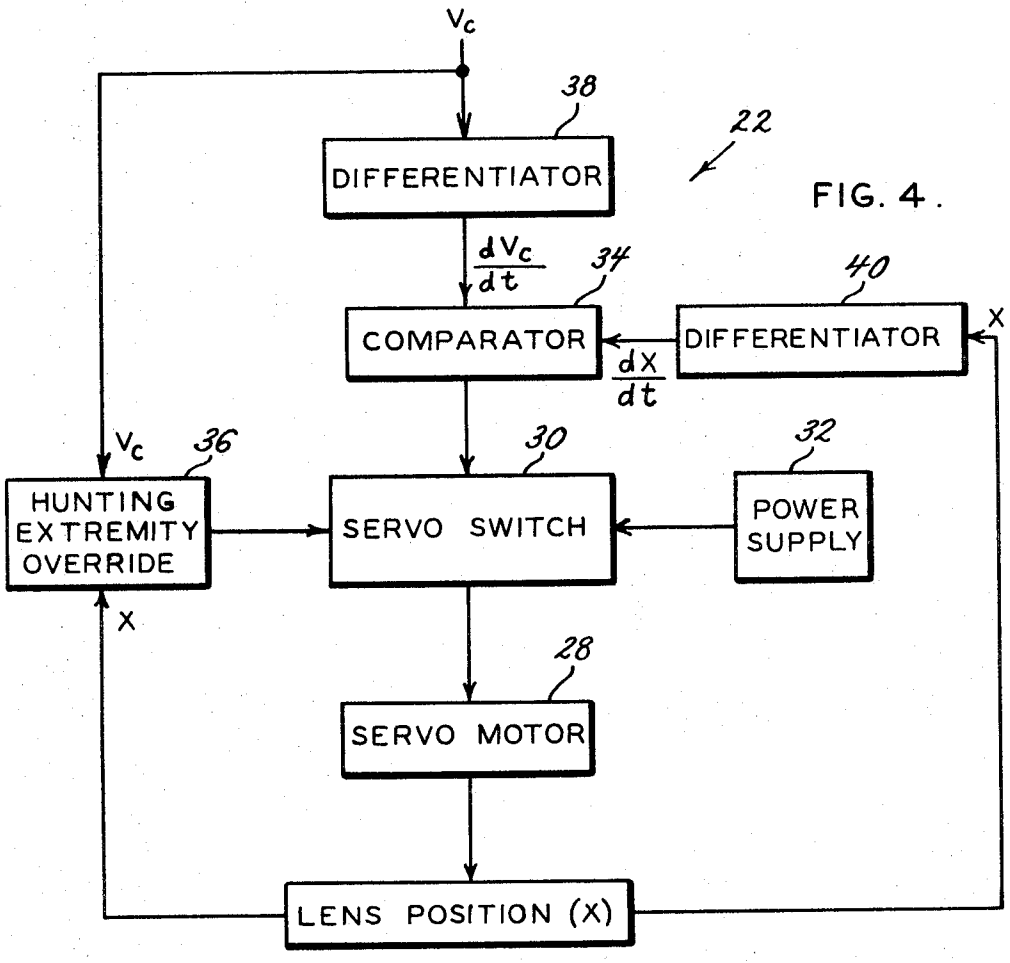


FIG. 4.

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AUTOMATIC FOCUSING MEANS USING AN ANALOG SIGNAL CORRELATOR

This is a continuation-in-part of my earlier filed copending application Ser. No. 552,795, filed May 25, 1966, now abandoned, and assigned to the same assignee.

The present invention relates generally to automatic control devices and the like, and more particularly to an automatic focusing control for cameras and other optical and electronic viewing devices.

The present invention teaches the construction and operation of novel means for automatically focusing a camera or similar device by sensing separate, distinct rays of light coming from an image, producing separate analogue signals characteristic of said selected distinct light rays, correlating said analogue signals to produce an output control signal responsive thereto, and using the correlated output to drive a focusing control in order to maintain a focused condition. So far as known, it has not heretofore been proposed to automatically focus a camera or other lens system by sensing and correlating analogue signals produced by means which detect and respond to variations in selected light rays coming from an image to be photographed or viewed. For these and other reasons the present invention represents an important advance in the art of automatic focusing devices. The present autofocus means can also be constructed to be extremely sensitive and fast acting, making them particularly well suited for focusing devices such as airborne and other moving cameras and the like which are used for taking pictures at high speeds. The present invention therefore teaches the construction and operation of an extremely fast-acting, sensitive and reliable automatic focusing device which requires little or no operator attention or skill and yet is able to maintain an image in focus under even the most severe operating conditions. In can readily be seen that the present device has wide application including many applications in addition to automatically focusing and some of these are suggested in the specification. The device can also be used with stationary cameras and related equipment which observe moving or otherwise changing images, and it can be used to focus television cameras and other photographic and viewing instruments as well.

It is therefore a principal object of the present invention to provide improved autofocus means.

Another object is to provide relatively inexpensive yet extremely fast-acting automatic focusing means.

Another object is to provide means for maintaining a focused condition on a rapidly changing and/or moving image.

Another object is to provide improved means for maintaining the focus of a camera located on a moving object or vehicle.

Another object is to provide autofocus means which require little or no attention by an operator.

Another object is to correlate analogue signals produced by means responsive to selected light rays and traces thereof in a field of view.

Another object is to provide improved means for generating control signals.

These and other objects and advantages of the present invention will become apparent after considering the following detailed specification which described a preferred embodiment of the subject invention in conjunction with the accompanying drawings which show schematic diagrams of a lens system equipped with automatic focusing means constructed according to the present invention and wherein:

FIG. 1 is a schematic diagram partly in block form showing one embodiment of an automatic focusing system constructed according to the present invention;

FIG. 2 is a schematic diagram similar to FIG. 1 showing another embodiment of the subject automatic focusing means;

FIG. 3 is a graph of typical correlator output voltage as a function of lens position; and,

FIG. 4 is a block diagram of a typical servomechanism for use in the device of FIG. 1.

Referring to the drawings more particularly by reference numbers, number 10 is a lens such as a camera lens which is

provided with suitable means for moving it along its optical axis in order to focus an image observed thereby on a film or other viewing station. The lens moving means may include a servomechanism or other motor means which when energized move the lens along its optical axis in order to maintain the camera in focus. In the embodiment disclosed the light from the image passes through the lens 10 and also through a slit 12 in a collimating device such as disc 14 which is located in the desired focal plane of the lens 10 and which is also the location in the device where a film strip (not shown) is to be located.

On the opposite side of the disc 14 from the lens 10 are positioned a pair of spaced photomultiplier devices 16 and 18. The spacing of the devices 16 and 18 back of the disc 14 is not critical, the important thing being that the angle subtended by the two detectors relative to the slit 12 must be no greater than the angle subtended by the outermost rays from the lens 10 with respect to the slit 12 when the lens 10 is extended to its most distant position from the disc 14. Each photomultiplier is positioned to receive and to respond to a different distinct ray of light coming from the image. The photomultipliers include means sensitive to the intensity and other characteristics of the light rays impinging thereon. The light-sensitive means in the photomultipliers may be of known construction. For example, they may include photoconductive wafers which produce analogue voltages responsive to the intensity of the light impinging thereon and changes therein. The analogue signals produced in each photomultiplier are amplified by suitable amplifier means and are fed as separate inputs to an analogue signal correlator circuit 20. The signal correlation circuit 20 may be similar to the analogue signal correlator circuit disclosed in Samuel E. Merrifield U.S. Pat. No. 3,413,850 issued Dec. 3, 1968 and assigned to the applicant's assignee.

The correlator circuit 20 included means for combining the analogue outputs of the photomultipliers 16 and 18 and to produce therefrom an output which is then used to energize a servomechanism 22 or other motor means connected to move the lens 10. The details of the construction and operation of the correlator circuit are disclosed in the above indentified Merrifield patent and a typical servomechanism will be described later in connection with FIG. 4. It is important to the operation of the correlator circuit 20 that the analogue signals received from the photomultipliers 16 and 18 be produced in response to exposure to different distinct light rays so that the signals produced thereby can be correlated. In the present autofocus application the signals are cross-correlated in order to produce an increasing or decreasing output to be able to drive the servo 22 in the desired direction. An increasing correlation output occurs when the two inputs to be correlator circuit are becoming more like each other and reaches a maximum or optimum condition when the correlation inputs, and hence the light rays observed by the detectors, are identical. A decreasing correlation output occurs when the two correlation inputs are becoming more different from each other. This can also be referred to as an increase in a negative direction or sense. This is necessary because focusing may require movement of the lens in both directions depending on how the image is changing.

The lens 10 can be substituted for by other forms of light-transmitting devices including devices such as prism-type range finders and the like which are independent of the camera lenses. The important thing is that each photomultiplier detect and respond to a different distinct light ray or light ray trace so that it will produce an analogue signal that varies in proportion to the intensity and other characteristics thereof. In some systems it may be necessary or desirable to use a spinning mirror or other means to artificially generate movements of the image relative to the detectors, although for a camera mounted on a moving vehicle such as an airplane this is not necessary because the actual movements of the image itself as seen by the camera usually establishes sufficient variation in the detected light ray traces to produce the necessary autofocusing. It is basic to the invention therefore, that

there be either (1) motion of the object relative to the subject system such as when the device is mounted in an aircraft or other moving device, or (2) if the object is fixed relative to the camera then it is necessary to generate movement of the image relative to the detectors, which can be accomplished by arranging so that either the disc 14 and its slit 12 be translated or oscillated in the film plane while holding the lens 10 and the detector devices 16 and 18 stationary or, alternatively, translate or oscillate the detectors as a unit parallel to the film plane while maintaining the lens and the disc 14 fixed.

When the lateral traces detected by the separate photomultiplier tubes 16 and 18 are in perfect correlation, i.e., when the two independent rays or traces are both superimposed on the film plane of the camera, the analogue signal correlator circuit 20 which correlates or compares the analogue outputs of the photomultipliers will produce a maximum signal cross-correlation output. This output will usually be close to but not necessarily exactly 100 percent correlation. In this context, 100 percent cross-correlation means that the light observed by each of the photomultipliers is the same. This depends upon the accuracy of the construction of the components, and the accuracy of the adjustment means included to balance the device and to make the outputs appear to be identical under these conditions. Any variation in the light reaching one or both photomultipliers which changes the correlation will reduce the cross-correlation output.

The output from the correlator circuit 20 is a signal which varies in accordance with the degree of the cross-correlation as determined by the correlation circuit.

For example, when the cross-correlation is at or near 100 percent the output of the correlator circuit will be a maximum. This means that the servomechanism 22 or other suitable operator has been driven to a position in which lens 10 focuses the optical system on the image. Changes in the correlator output will produce corresponding changes in the position of the lens as will be shown. There is no claim to novelty in the present invention of the mechanism to measure the correlation of the lens motion with a correlation increase and to accomplish switching if the correlation change is in the wrong direction to improve the focus. Such means are well within the state of the art and can be accomplished electronically or electromechanically.

The image motion caused by relative movement between the camera and the image in existing equipment has seriously degraded the quality and effectiveness of the existing devices, and attempts to solve the problems of autofocusing has resulted in the production of complicated, expensive devices which have required special image motion compensation means. The available devices have therefore not been satisfactory and have also been slow acting and complicated and difficult to adjust and operate. The present automatic focusing means overcomes all of these and other shortcomings and is an extremely flexible and versatile device. Furthermore, the subject device preferably includes stationary photomultipliers which represent an advantage in structure and cost particularly in devices constructed to be used with high relative velocities between an image and a camera.

The system shown in FIG. 2 is similar to the system of FIG. 1 and corresponding parts are numbered the same but with the numbers primed. The main difference between the system of FIG. 2 and the system of FIG. 1 is that the system of FIG. 2 is shown having a four-sided rotating mirror 24 which is connected by shaft 25 to be rotated by drive motor 26. This is done to produce the relative motion necessary in the system so that the rays impinging on the detectors 16' and 18' will generate the correlation input signals. Except for these differences, the system of FIG. 2 operates substantially the same as the system of FIG. 1. The system of FIGS. 1 and 2 may also include other collimating slit means associated with the detectors to improve the operation.

The details of a typical servomechanism 22 and of the components thereof are illustrated in FIG. 4 and include a reversible servomotor 28 which is operatively connected to move the lens 10 when energized. The controls for the servomotor 28 include a servoswitch 30 which connects a power supply 32 to the servomotor 28 with controllable polarity so as to drive the motor 28 in the appropriate direction as required to maintain the lens in focus. The servoswitch 30 operates under commands or instructions from either a comparator circuit 34 or a hunting extremity override circuit 36 both of which will be described. The output voltage from the correlator circuit 20 which is labeled V_c is applied to the input of a differentiator circuit 38 and also to the input of the hunting extremity override circuit 36. The differentiator circuit 38 differentiates the signal V_c as to time and produces an output signal represented as dV_c/dt. Differentiator circuits capable of performing this operation are well known in the electronics art.

Another differentiator circuit 40 similar in construction to the differentiator 38 differentiates another signal which represents the position of the lens 10, which is represented as position x, and produces an output dx/dt which represents the rate of change of lens position with respect to time. The comparator circuit 34 receives as inputs the output dV_c/dt of the differentiator circuit 38 and the output dx/dt of the differentiator 40. The comparator circuit 34 operates on the sense and not on the magnitude of the derivatives dV_c/dt and dx/dt in the following manner:

When the polarity of dV_c/dt and dx/dt are the same, either both positive or both negative, the comparator circuit 34 which controls the servo switch 30, will operate to cause the servomotor 28 to move the lens 10 in a positive direction which is the direction in which x, the lens position, is increasing. This positive direction of lens movement normally increases the distance between the lens 10 and the collimating slit 12 as shown in FIG. 1. Referring to the graph in FIG. 3 which is a plot of lens position against correlator output for a given image distance, this means that the lens 10 will move from a point represented on the graph by point B to point C.

On the other hand, when dV_c/dt and dx/dt have opposite signs from each other, that is when one is positive and the other is negative, the comparator circuit 34 will produce an output which will activate the servo switch 30 in a reverse polarity so that the servomotor 28 will move the lens in a direction of decreasing x or to the left on the graph of FIG. 3. Under these conditions the lens will be moved from a point such as the point D toward the point C. Under both conditions described above, as soon as the lens position moves from point B to point C or from point D to point C the reverse situation from the situation which caused the lens to be moved will exist, and will prevail so that the motion of the lens will reverse. The lens position will therefore oscillate within a narrow band centered about the optimum or in focus position represented by point C. Damping means should also be included to keep the hunting oscillations as small as possible about the point C.

The hunting extremity override circuit 36 is provided to cover situations where the lens is outside of the range of normal operation or near the extremities of its travel. The override circuit 36 in addition to receiving the output V_c of the correlator 20 also receives signals x which represent the position of the lens 10. The override circuit 36 is included in the servo system 22 to provide for those situations near the extremes of travel of the lens 10 where the correlator output voltage V_c is below a certain established threshold voltage designated in FIG. 3 by the line V_t. The threshold voltage V_t should be sufficiently high so that the correlator output V_c is not masked by internal noises and has sufficient magnitude to give a useful signal to the differentiator circuit 38. The override circuit 36 is connected to control the servo switch 30 so that it will power the servomotor 28 to drive the lens in one direction or the other, it does not matter which direction initially, unless or until the correlator output voltage V_c exceeds the threshold voltage V_t. In the event the lens position moves to the extreme limit of its movement in one direction without V_c exceeding V_t then the override circuit 36 will activate the servo switch 30 to reverse the direction of motion of the servomotor 28 thereby causing the lens to travel in the opposite

direction until V_c exceeds V_t. Whenever V_c exceeds V_t the override circuit 36 will instruct the servo switch 30 to operate only on further instructions from the comparator circuit 34 in accordance with the description above, and under these conditions, the override circuit 36 will be disengaged or will become inoperative.

The override circuit 36 can be even more clearly understood by referring to FIG. 3. If under the conditions shown in FIG. 3 the lens 10 starts at the point A and the servo switch 30 is set initially to move the lens in a positive direction in which the lens position x is increasing, then the correlator output voltage V_c will increase along the curve until it exceeds V_t after which the comparator circuit 34 will take over and move the lens to point C and past on the curve. If on the other hand, the lens starts at the point A with the servo switch 30 set to move the lens in a direction in which its position x is decreasing, or toward the left extremity of the lens travel, then the override circuit 36 will reverse the polarity of the servo switch 30 when the extremity condition is reached and will restart the lens motion in the opposite direction back toward the point B. A reciprocal set of commands and motion will occur if the lens 10 starts at a position such as at the point E instead of A, in which case the lens will move either toward the point D and then under control of the circuit 34 toward the point C or it will go to the extremity of its travel first and thereafter be reversed and returned to the point D and then to C. The particular form of servomechanism disclosed in FIG. 4 can be varied substantially from that shown without departing from the basic concepts of the present invention.

Thus there has been shown and described novel means for automatically focusing a camera or similar device on an object particularly where relative motion takes place between the camera and the image, which means fulfill all of the objects and advantages sought therefor. Many changes, modifications, variations, and other uses and applications of the subject device will, however, become apparent to those skilled in the art after considering this specification and the accompanying drawings which disclose preferred embodiments of the subject device. All such changes, modifications, variations, and other uses and applications of the subject device which do not depart from the spirit and scope of the invention are deemed to be covered by the invention which is limited only by the claims which follow.

I claim:

1. Means for automatically focusing an optical system comprising an optical system having a lens for observing an image in a field of view movable relative thereto, said lens focusing light from the image in a plane, motor means operatively connected to move the lens, said last-named means including means for energizing the motor means to move the lens in a direction to maintain the image observed by the lens in focus on the plane, said motor-energizing means including a pair of spaced light-sensitive elements positioned on the same side of the plane in positions to respond to different distinct light rays passing through the lens from the image during movement of the image relative to said system including said light-sensitive elements, each of said spaced light-sensitive elements including means for producing an electric signal which varies in response to the characteristics of the respective observed light rays from the image, means for correlating said signals to produce a correlation output signal representing the degree of correlation therebetween, said correlating means producing a maximum output signal whenever the lens is in focus, and means connecting the correlation means to the motor means to energize the motor means by said correlation output signal to maintain the optical system in focus, said motor means being energized by said correlation output signal to move the lens whenever the output of the correlator is less than maximum, the direction in which the lens is driven by the motor preferably being in a direction to increase the output of the correlating means toward the maximum output condition.

2. The automatic focusing means of claim 1 including means to optically move the image relative to the light-sensitive elements whereby said light-sensitive elements observe moving traces of the distinct light rays.

3. Means for automatically focusing an optical system positioned to observe an image movable relative thereto comprising an optical system having a lens positioned to observe an image, said lens focusing light from the image in a focal plane, motor means operatively connected to move said lens, means for energizing said motor means to move said lens in a direction to keep the image observed by the optical system focused on the plane, said last-named means including a pair of light-sensitive elements positioned on the same side of the image plane to observe different selected image light rays observed by the optical system, each of said light-sensitive elements including means for producing a signal which varies with the characteristics of the respective image light ray observed thereby, means for producing relative movement between the observed image and said light-sensitive elements, an analogue signal correlating circuit having separate inputs connected respectively to receive the signals produced by the said light-sensitive elements, said correlating circuit including means to correlate the signals received at the separate inputs and to produce an output signal corresponding to a correlation function thereof, said correlating circuit producing a maximum output whenever the optical system is in focus, and means for connecting the correlating circuit to the motor means to energize the motor means with the correlation output signal to move the lens in a direction to maintain the optical system focused on the observed image.

4. The means for automatically focusing an optical system defined in claim 3 wherein said optical system includes light-collimating means positioned between the lens and the light-sensitive elements, said light-collimating means including an apertured member positioned in the focal plane and means for predeterminately moving said apertured member.

5. The means for automatically focusing an optical system defined in claim 3 wherein said motor means include a servomechanism.

6. The means for automatically focusing an optical system defined in claim 3 wherein said optical system includes a mirror positioned to reflect light from the image toward the light-sensitive elements, and means for predeterminately moving the mirror to cause relative movement between the light rays and the light-sensitive elements on which they impinge.