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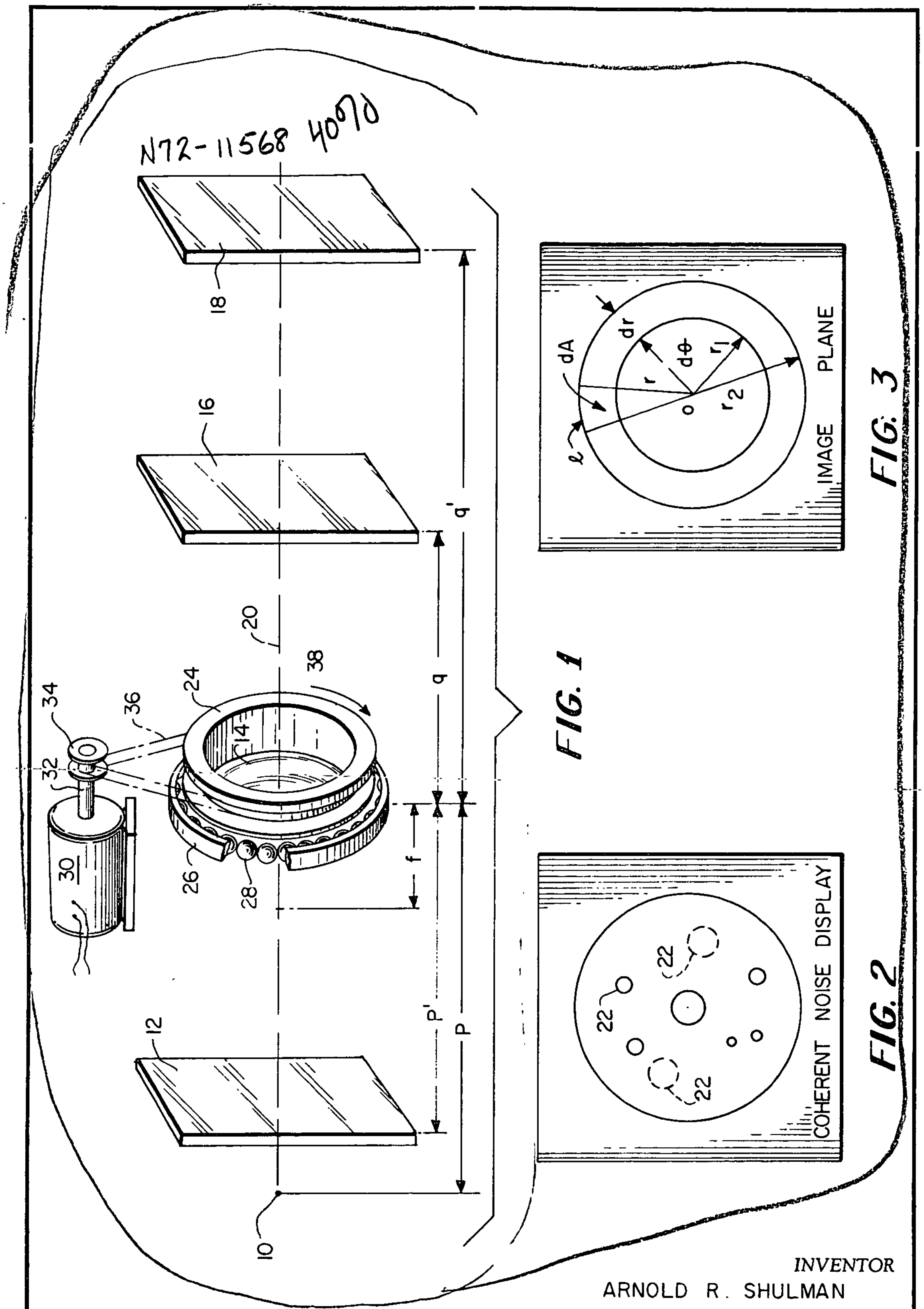

FIG. 1

FIG. 2

FIG. 3

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Publish, Fig. 1

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NASA Case [illegible] GSC 11,133-1

METHOD AND APPARATUS FOR ELIMINATING COHERENT NOISE IN A COHERENT ENERGY IMAGING SYSTEM WITHOUT DESTROYING SPATIAL COHERENCE

The invention generally relates to energy imaging systems and particularly concerns a technique whereby coherent noise associated with coherent energy systems such as optical light imaging systems can be eliminated.

In the preferred inventive embodiment such as depicted in Figure 1, the invention comprises the improvement in a coherent energy imaging system having a source of coherent light 10, an input signal plane 12, an output image plane 18, and at least one image lens 14 disposed between the planes, wherein means are provided to effect rotation of the lens 14 about its optical axis 20 during exposure. As illustrated, such rotation effecting means may comprise a motor-driven lens mounting journalled for rotation. Other means for effecting relative movement between the lens and the input and output planes may be utilized.

The instant invention serves to minimize and essentially eliminate undesirable coherent noise diffraction patterns in the output image plane such as would be caused by bubbles, dust, and defects in and/or on the lens, by distributing the energy density of the coherent diffraction patterns over an area of the output image plane such that it can be ignored, and with relatively little, if any, image degradation as a result. It should be appreciated that the instant invention has applicability to other forms of coherent energy imaging systems.

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APPLICATION FOR LETTERS PATENT

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT I, ARNOLD R. SHULMAN, a citizen of the United States of America and a resident of the State of Maryland, have invented certain new and useful improvements in METHOD AND APPARATUS FOR ELIMINATING COHERENT NOISE IN A COHERENT ENERGY IMAGING SYSTEM WITHOUT DESTROYING SPATIAL COHERENCE of which the following is a specification:

ABSTRACT OF THE DISCLOSURE

A method and apparatus is disclosed for substantially eliminating coherent noise in a coherent energy imaging system and specifically in a light imaging system of the type having a coherent light source and at least one image lens disposed between an input signal plane and an output image plane. In the preferred embodiment thereof, the invention contemplates illuminating the input signal plane with the light source, and during the exposure, rotating the lens about its optical axis. In this manner, the energy density of coherent noise diffraction patterns as produced by imperfections such as dust and/or bubbles on and/or in the lens is distributed over a ring-shaped area of the output image plane and is reduced to a point wherein it can be ignored. Importantly, the spatial filtering capability of the coherent imaging system is not affected by this noise elimination technique.

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefore.

BACKGROUND OF THE INVENTION

This invention generally relates to energy imaging systems and particularly concerns a technique whereby coherent noise associated with coherent energy systems such as optical light imaging systems can be eliminated.

Energy imaging systems in general, such as optical processing interfaces, are part of a rapidly advancing and important technology. Optical data processing, for example, has found widespread use since it permits, with only a relatively simple configuration of lenses and peripheral apparatus, the implementation of mathematical functions such as multiplication, Fourier transformation, correlation, and convolution. The primary advantages of such optical data processing systems lies in their speed and simplicity in performing various computations and such systems can be conceived of as analog methods of computation which permit, for example, a two dimensional Fourier transform to be obtained instantaneously, visibly, and without complex programming or equipment.

From a structural viewpoint, a typical optical imaging system utilizes a coherent light source, an input or signal plane, an imaging or transformation lens, and an image or spectral plane, all through which light passes and is operated upon. For example, if the input signal plane is provided with a transmission function thereon and then illuminated with a uniformly coherent light source, the transmission function or spectral content thereof will be reproduced through the lens at the output image plane. This output image can be spectrally filtered through the provision of optical filtering mechanisms which may be disposed between the lens and the output image plane, this filtering operation being simple and requiring only blocking of the light at points corresponding to unwanted frequencies. By such suitable filtering, the spectral distribution corresponding to the spectral content of the input signal can easily be modified in both phase as well as in amplitude and it is therefore possible to enhance various types of degraded images by such filtering. Optical filtering therefore can eliminate undesirable elements in an image or enhance others, and degraded images of various types can be filtered to improve image definition and contrast. Additionally, certain blurs and defocusing effects in the image can likewise be filtered.

Such optical imaging systems or optical data processing apparatus are not, however, entirely trouble-free. For example, optical imaging systems utilizing coherent light, as well as imaging systems utilizing other forms of coherent electromagnetic and other energy, often introduce objectionable noise into the output image plane. Dust and bubbles both on and in the lenses so utilized cause most of the noise in the output image, this noise degrading the image and usually appearing as bull's-eye diffraction patterns therein. It is, of course, desirable to remove this objectionable coherent noise. Yet, the prior art approaches have met with limited success. Importantly, not only must the objectionable coherent noise be eliminated, but it must be done in a fashion wherein the spatial coherence of the light or energy is not destroyed and wherein spatial filtering of the input plane is still permitted.

SUMMARY OF THE INVENTION

It is thus a primary object of the instant invention to provide both the technique and the apparatus for substantially eliminating coherent noise in a coherent energy imaging system of the types described in a manner wherein the spatial coherence of the energy is not destroyed and wherein spatial filtering of the input plane is still permitted.

More specifically, it is an object of the instant invention to provide a technique and apparatus by which the degrading affects of dust, bubbles, and other imperfections on and in lenses within an optical imaging system utilizing coherent light, for example, are minimized.

It is still another object of the instant invention to provide such a noise eliminating technique and apparatus therefor which is extremely simple in design and economical in cost.

These objects as well as others which will become apparent as the description proceeds are implemented by the instant invention which, as aforestated, contemplates the provision of a novel method of eliminating coherent noise in a coherent energy imaging system and particularly in a coherent light imaging system of the type utilizing a coherent light source and at least one image lens disposed between an input signal plane and an output image plane. Conceptually and in a system as above-described, the invention contemplates to effect relative and synchronized movement such as rotation between the input and output planes, on the one hand, and the imaging lens on the other hand, during each exposure of the input plane by the light source. Importantly, the relative rotation is effected about the optical axis of the lens and, as will be explained hereinbelow, the objectionable coherent noise is substantially eliminated in this simple matter, without destroying spatial coherence.

In a preferred emobidment, the image lens itself is rotated about its optical axis during exposure of the input plane, the rotation preferably, though not necessarily, being through at least one complete revolution of the lens during each exposure. In yet another preferred inventive embodiment, the imaging lens is continuously rotated at constant speed during and between each exposure, thus providing the advantages of more stable operation.

In operational effect, this novel technique serves to minimize the undesirable coherent noise diffraction patterns in the output image plane of the system, which diffraction patterns are produced by imperfections on and/or in the lens, by distributing the energy density of the coherent noise diffraction pattern over an area of the output image plane such that it can be ignored, and with relatively little, if any, image degradation as a result.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention itself will be better understood and additional objects, features and advantages thereof will be apparent from the following detailed description of a preferred inventive embodiment, this description referring to the appended single sheet of drawing wherein:

Figure 1 is a perspective view of a coherent optical imaging system typical of that to which the instant invention relates, illustrating the novel inventive technique of effecting rotation of the imaging lens during each exposure;

Figure 2 is a pictorial illustration displaying coherent noise produced at the output image plane by imperfections on and/or in the imaging lens; and

Figure 3 is a schematic representation of the conceptual manner in which rotation of the lens in accordance with the instant invention serves to minimize undesirable coherent noise by distributing the energy density thereof over a wide area of the output-image plane.

DETAILED DESCRIPTION OF A PREFERRED INVENTIVE EMBODIMENT

Referring initially to Figure 1 of the appended drawings, an exemplary single lens coherent optical imaging system is depicted. Such a system could, for example, form an optical spectrum analyzer and will be seen to comprise a source 10 of coherent energy or radiation such as light which uniformly illuminates an input or signal plane schematically illustrated as at 12. Source 10 may itself comprise an optical lens system containing a rotating lens as discussed hereinbelow to produce a uniform collimated coherent beam, or a coherent energy source sufficiently far from input plane 12 so as to uniformly illuminate same. An image and/or Fourier transform lens 14 is also provided as is a filter plane, or, more specifically in this instance, a Fourier transform spectrum plane 16, and an output image plane 18. Each of the aforesaid elements are disposed in alignment about the optical axis 20 of the imaging lens 14.

As can be seen from Figure 1 of the drawings, the spectrum of the signal in the input signal plane 12 appears at plane 16. Considering now a coherent light source 10, which light source is illustrated herein as being a point source infinitely far from plane 12, the spectrum location can be found from the lens formula and determines the spectrum location for any image illuminated in plane 12:

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

where

f = focal length of the lens 14;

p = object distance from the lens and, in this instance, the distance of the point source 10 from the lens 14;

q = image distance, i.e. the distance from the lens 14 to the image of the point source 10.

Likewise, the location of the image output plane 18 of the signal in the input plane 12 can be found from the lens equation

$$\frac{1}{f} = \frac{1}{p'} + \frac{1}{q'}$$

where

f = focal length of the imaging lens 14;

p' = the distance from the input signal plane 12 to the lens 14;

q' = distance from the lens 14 to the output image plane 18.

The above-described single lens coherent optical imaging system permits spatial filtering of a signal in plane 12 whose spectrum prior to filtering and imaging appears in plane 16 and produces an image of the signal in plane 12 at the output plane 18. Yet, this single lens coherent optical imaging system is only exemplary of the environment to which the instant invention relates as other optical imaging systems having one or more lenses could be utilized, such as optical filters, optical correlators, channelized optical correlators, and the like. Additionally, while the input light source 10 has been illustrated as comprising a point source of coherent light, other types of energy sources could also be utilized such as a source of coherent light which generates a collimated beam, the wave forms of which are in a plane rather than in a spherical wave in the case of a point source. The preferred inventive embodiment contemplates the utilization of a laser source though it should be understood that a mercury arc source of light with suitable filtering could likewise be utilized or, in fact, any source energy or radiation exhibiting temporal coherence providing a monochromatic beam, with some spatial coherence. Furthermore, it has been found that in some astronomical imaging systems, a non-coherent light source might also be used to advantage.

Proceeding with the description and with attention now directed to Figure 2 of the appended drawings, a typical output image display such as would appear at the output image plane 18 through illumination of the light source 10 is shown. As should be noted, coherent noise exists in this output image, this coherent noise being depicted as a plurality of small bull's-eye patterns 22 distributed over the image. These undesirable noise patterns are primarily caused by dust and dirt on the lens 14 surfaces, bubbles in the lens, or other imperfections on the lens surfaces. Quite obviously, these noise patterns highly degrade the output image and adversely affect the operation of the optical imaging system. In an effort to reduce these undesirable noise patterns to a minimum, prior art approaches in this area concentrated on a careful selection of the lenses utilized in the optical imaging system such that there was a minimum of bubbles and defects in the glass. Additionally, with prior art systems, the glass surfaces of the lenses had to be kept extremely clean even to the point of placing the entire optical imaging system in a vacuum. Of course, such careful selection of lenses is an expensive undertaking and still is not completely satisfactory since even the most minute defect in a lens is greatly exaggerated in coherent light. Additionally, placing an entire optical system in a vacuum makes working conditions quite difficult and markedly increases the associated expense.

Applicant has found, however, that these undesirable noise patterns in the output image plane of an optical imaging system can be substantially eliminated by the simple and highly novel technique of rotating the imaging lens 14 about its optical axis 20 during exposure, i.e. illumination of the input signal plane 12 by the light source 10. In effect, by so rotating the lens during exposure, any coherent noise developed by lens "imperfections" as above-discussed is distributed over a large area of the output image plane and thus reduced to such a level as to render it negligable. As should be readily apparent, the advantages of this simple technique of eliminating coherent noise are many-fold in that selection of lenses utilized in the optical imaging system is simplified, the so-called "clean room" requirements are reduced, and low noise coherent images can now be created utilizing realatively low cost equipment.

The conceptual technique by which the instant invention operates and an illustration of the efficacy of the invention can be found by reference to Figure 3 of the inventive sheet of drawings wherein the image output plane 18 of the system of Figure 1 is again schematically represented. The point at which the optical axis 20 of the exemplary imaging system of Figure 1 intercepts this image plane is labelled O. As explained above, any minute dust particle or other imperfection on/or in the lens 14 will cause a bull's-eye diffraction pattern such as 22 in this image plane. Conceptually, a small area dA of the noise diffraction pattern in this image plane can be considered and the light energy during exposure incident on this small area dA can be defined as E. This is the coherent noise energy and, of course, this noise must be minimized to avoid image degradation. The noise energy density for this small area dA of the output image plane can be written:

$$\text{Noise energy density (No lens rotation)} = I = \frac{E}{dA},$$

where

$$dA = \ell dr.$$

By rotating the lens 14 about the optical axis 20, this noise energy can be distributed over the area of a ring produced by rotating the area dA, i.e. instead of the noise energy striking only the area dA, this noise energy can be distributed over the larger ring area:

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$$A = \pi(r_2^2 - r_1^2) = \pi(r_2 + r_1)\ (r_2 - r_1).$$

From the geometry of the concentric circles of Figure 3, it is apparent that

$$r_2 - r_1 = dr$$

and

$$r_2 + r_1 = 2r_1 + dr.$$

Using these relationships the expression for the area can be written

$$A = \pi (r_2 + r_1) \quad (r_2 - r_1)$$

$$A = \pi (2r_1 + dr) \ dr = 2\pi r_1 dr + \pi dr^2.$$

Since dr is very small, the term dr^2 can be dropped, giving

$$A = 2\pi r dr.$$

The original energy E is then distributed over a ring of area

$$A = 2\pi r dr.$$

The noise energy density for this ring area can be written

$$\text{Noise energy density (with lens rotation)} = I' = \frac{E}{2\pi r dr}.$$

The ratio of the energy density for the lens 14 rotating and not rotating is

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$$\frac{I'}{I} = \frac{\frac{E}{2\pi r dr}}{\frac{E}{dA}} = \frac{dA}{2\pi r dr} = \frac{\ell dr}{2\pi r dr} = \frac{\ell}{2\pi r}.$$

From this it is clear that when

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$$r \sim \ell, \ \frac{I'}{I} = \frac{1}{2\pi} \sim \frac{1}{6}$$

$$r \sim \frac{\ell}{3}, \ \frac{I'}{I} \sim \frac{1}{2}.$$

If ℓ is considered as roughly the diameter of the noise spot in the image plane and r as its distance from the optical axis, then unless the noise spot is on the optical axis (or extremely close to it), its energy will be distributed such that it can be ignored.

By selection of lenses it is possible to keep the noise minimized by assuring that the bubbles, dust, and lens defects are not on or near the optical axis.

Expressing the above mathematical development in words, the instant invention serves to minimize and essentially eliminate undesirable coherent noise diffraction patterns in the output image plane by distributing the energy density of the coherent noise diffraction patterns over an area such as a ring-shaped area of the output image plane during exposure by the technique of rotating the lens about its optical axis.

While the preferred embodiment of the instant invention has been described as being such that the exemplary lens 14 is itself rotated about its optical axis during exposure, from a more general point of view and consistent with the invention, the noise in the light imaging plane can essentially be eliminated by effecting relative and synchronized movement such as rotation between 1) the input and output planes 12 and 18, respectively, and 2) the lens 14, about the optical axis of the lens during the exposure. Specifically, instead of rotating the lens during the exposure and maintaining stationary the input and output planes as is the case in the preferred inventive embodiment, the lens itself might remain stationary and the input and output planes may be synchronously rotated about the optical axis of the lens during each exposure.

Importantly, it has been found through tests utilizing high frequency Ronchi rulings, that the technique of the instant invention whereby coherent noise is eliminated by rotating the lens, for example, does not affect the spatial filtering capability of the coherent imaging system. In this environment, this is an extremely important advantage and the reason for this capability of the invention is that the coherent noise diffraction patterns are only significant in the output image plane 18 of the system shown in Figure 1, and not in the spectrum or filtering plane 16, but the image of the spectrum in plane 16 remains stationary during lens rotation.

With the technique of the instant invention now firmly in mind, attention is once again directed to Figure 1 of the appended drawing wherein an exemplary apparatus effecting rotating of the lens is schematically illustrated. Since the technique of the instant invention, in the preferred embodiment thereof, requires the lens to be rotated about its optical axis during exposure so as to eliminate the noise diffraction patterns caused by "imperfections" in and/or on the lens, care must be taken to assure that the lens rotation is about its optical axis. Thus, proper selection must be made of a rotatable lens mount, for example, such that the axis of symmetry of the lens mount and the optical axis of the lens coincides. In this respect, and as an example, the lens 14 can be disposed in a lens mount 24, which mount is itself rotatably disposed and journaled in a housing 26 by bearing means 28 such as Fafnir bearings or other suitable devices. A motor 30, such as an electric motor having a shaft 32 coupled to a drive wheel 34, is provided for effecting rotation of the lens 14, mechanical coupling being provided between the drive wheel 34 and the lens mount 24 by means of a flexible belt 36, for example. Thus, when the motor means 30 operates, lens 14 will be rotated in the direction of the arrow 38. As should be appreciated, the specific configuration of the mechanical apparatus above-described can be varied by one skilled in the art, as the prime requirement in the preferred embodiment is a means to effect rotation of the lens about its optical axis during exposure.

Continuing and referring once again to Figure 3, it has been seen that rotation of the lens 14 serves to distribute the energy density of the noise defraction pattern over a ring-shaped area of the output image plane so as to effectively eliminate the undesirable affects of the noise. An optimum minimization may occur for example, when during each system exposure wherein the light source 10 illuminates the input signal plane 12, the lens 14 effects one complete revolution, as can be appreciated from a review of the mathematical derrivations of Figure 3 herein above. Thus, the inventive system may operate, though not necessarily operate, such that the lens 14 is intermittently rotated through one complete revolution every time a system exposure occurs. Alternatively, it has been found that advantages can be obtained when the lens is continuously rotated at constant speed about its optical axis, even between system exposures. Such continuous rotation provides additional system stability due to the gyroscopic affect of constant lens rotation.

While the foregoing description referred specifically to a coherent light imaging system as the environment of the preferred inventive embodiment, those skilled in the art will readily recognize the applicability of the inventive principles hereindisclosed to other forms of coherent energy imaging systems. It should now be apparent that the objects initially set forth at the outset of this specification have been successfully achieved.