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SINGLE-FOCUS IMAGES RESTORED FROM CONVENTIONALLY-RECORDED SUPERPOSED CODED MULTI-FOCUS PHOTOGRAPHS

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The experiments reported in this communication are in some parts similar to the famous experiments first described by W.E.Glenn, and subsequently by Armitage and Lohmann, and, independently by P.F. Mueller and F.Bestenreiner and R.Deml. However, ours were done for quite different reasons, namely as an alternative to our previously-described holographic image deblurring methods.

We have recently shown that it is possible to use two different holographic methods [1-5] to extract greatly sharpened 'deblurred' images from photographs which have been blurred by accident or deliberately coded, for instance in view of 'aperture synthesis' applications. Simultaneously, for about one year, we have been exploring coding methods which would permit us to restore single-focus images from a conventionally recorded, suitably coded multi-focus photograph. The results of our work and the principles of our method are given in figs. 1 and 2, as a model. The decoded single-focus image shown in fig. 2a was extracted from the coded multi-focus photograph shown above by using the first-order spectrum indicated by the arrow. The corresponding image component (fig. 2a) was coded (as shown in fig. 1) by a 1000 lines/ inch (approximately 40 lines/mm) amplitude ('Ronchi' type) grating kindly furnished by Max Levy and Co., Philadelphia [6]. The other image component superposed in the photograph of fig. 2a was considerably out of focus and coded with the same grating oriented at about 90^o from the in-focus coding position. (The decoded out-of-focus component is shown in fig. 3.) In the case shown, the object was a well-known Kodachrome transparency, photographed at approximately unit magnification in an enlarger using a Schneider f= 150 mm objective, at f/5.6. The 'out-of 'focus' image component was recorded in the same arrangement, but with a blur (spread) function diameter of approximately 1 mm, carefully aligned with the 'in-focus' point image of the other component. In a similar experiment, shown in fig. 2b, and with a similar blur function, we combined an 'out-of-focus' displacement with

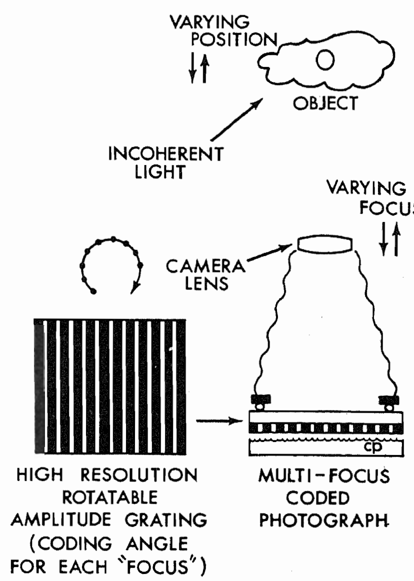


Fig. 1. Schematic diagram illustrating the principle of the recording of 'coded' multi-focus photographs. The method shown may be used for extracting 'single-focus' images (see fig. 2) from a suitably coded superposition of components in a single 'multi-focus' photograph in a great number of different situations, including object (or subject) motions and displacements, as well as camera focus-imperfections and motions.

a displacement orthogonal to the optical axis, however with an earlier grating of only 20 lines/ mm. The excellent quality of the decoded image shown in fig. 2b verifies that our method permits us to restore 'in-focus' images from coded photographs containing a superposition of 'out-of-focus' components, on the one hand, and, on the

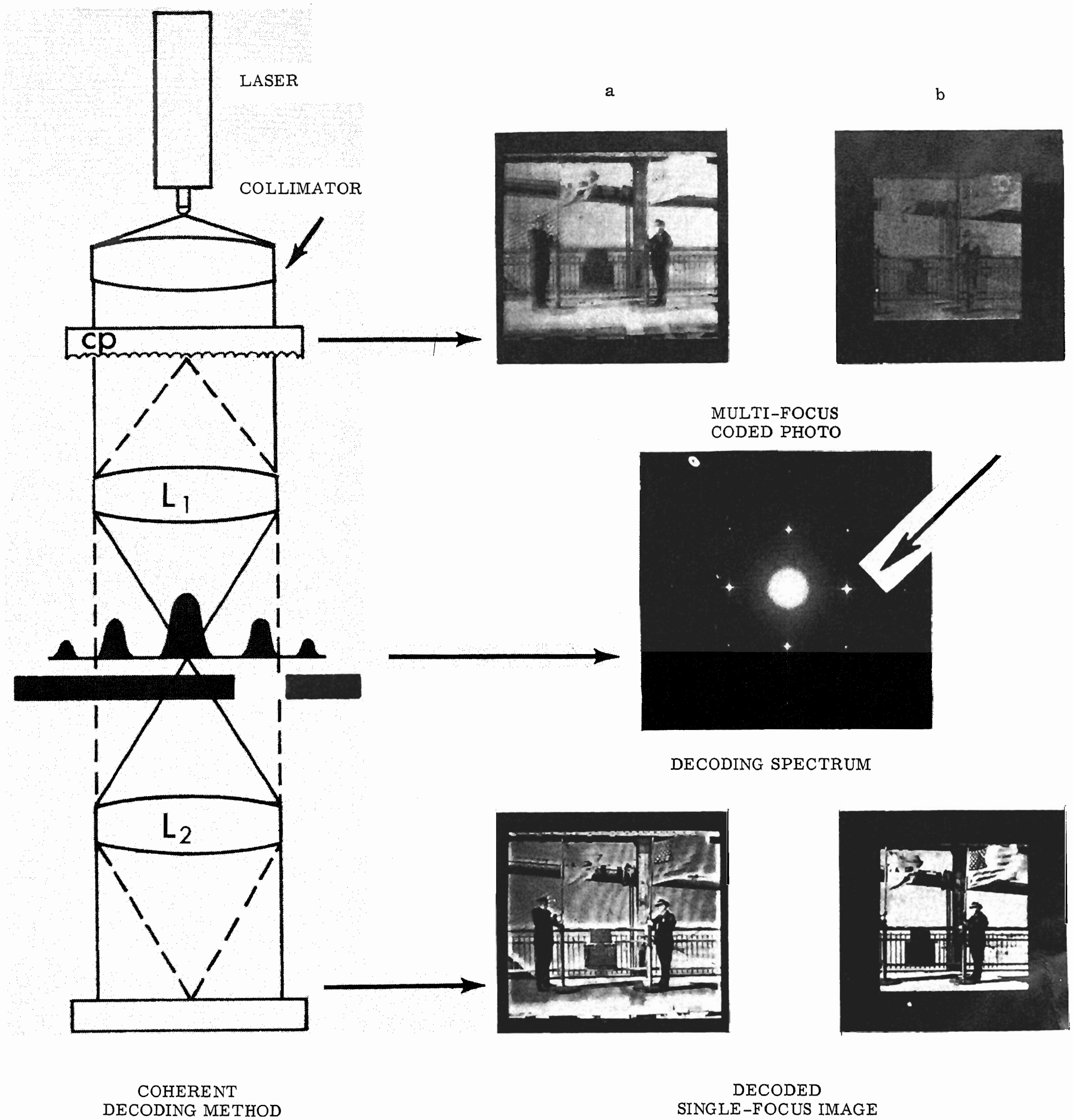


Fig. 2. Spatial filtering arrangement used for decoding (left) and experimental results (right). The laser used in our work was a Spectra Physics Model 125 (nominal 100 milliwatt) helium-neon laser (6328 Å). The lenses L_1 and L_2 had focal lengths of 15 inches (about 38.1 cm). The description of the experimental results shown in figs. 2a and 2b is given in the text.

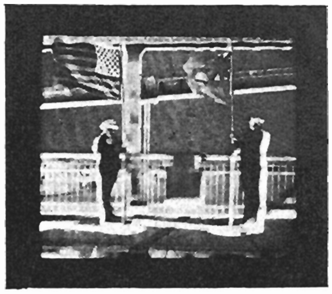
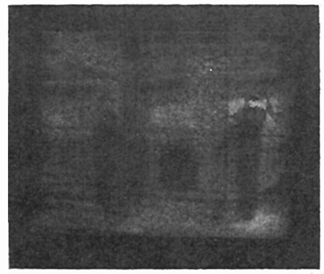


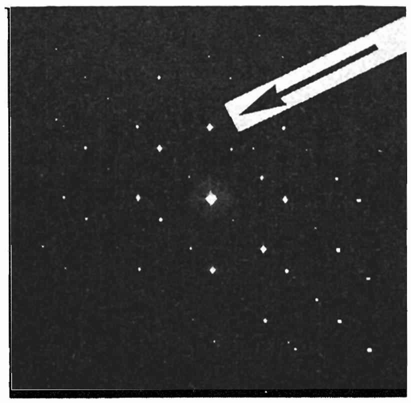
Fig. 3. Out-of-focus component image extracted from the multi-focus photograph of fig. 2a (see text. Compare with 'in focus' component image extracted from same photograph and shown as 'decoded single-focus image' in fig. 2a).

other, various translation and rotation components. That our method of 'single-focus image restoration' should work not only for the case of two component images, used for illustration, but indeed for a considerable number of similarly superposed coded photographs, may be directly concluded from the original "color-projection system" work by W. E. Glenn [7], from the comparable "theta modulation" work by Armitage and Lohmann [8], and more specifically also from the recent detailed analysis given in the work on "carrier-frequency photography" by Bestenreiner and Deml [9] and on "linear multiple image storage" by Peter Mueller [10], even though these authors [7-10] did not deal with or suggest the 'single-focus image restoration' application which we present here. The work of refs. [7-10] dealt with classes of situations where all of the coded image components were 'in focus'. However, the detailed analysis given in refs. [7-10] may be readily transposed to our new application, so that no further elaboration is required within the framework of this brief communication. It should also be clear that our method should permit us to restore a single 'in focus' multi-color image from a black-and-white photograph recorded with a coded superposition of the color components in the photograph, in combination of our new method with that first described by W. E. Glenn [7]. We have successfully extracted a very good 'in-focus' image from a superposition with *two* 'out-of-focus' images (2.2 mm dia. blur circle). The early result is shown in fig. 4.

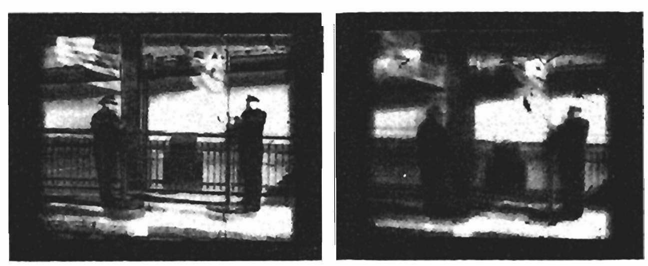
It sould finally be clear that our 'single-focus image restoration' method may be used for 'compensation' of effects resulting from object (or subject) displacements or motion as well as for



THREE SUPERPOSED
CODED PHOTOS



DECODING SPECTRUM



IN FOCUS OUT OF FOCUS
DECODED IMAGES

Fig. 4. Single-focus decoding in the case of coded superposition of three images, one 'in focus' and two 'out-of focus' (with a blur-circle diameter of 2.2 mm). This early result helps to verify the prediction described in text. Arrow points to 'in focus' spectrum used to decode 'in focus' image.

those resulting from imperfect camera focus or motion. The general 'diffraction gratings' background for our work is in ref. [11] and that on holography in ref. [12].

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