SECRET

24 JUN 1966

ANALOG IMAGE RESTORATION

1. PROBLEM:

To extract more information from degraded imagery.

2. FACTS BEARING ON THE PROBLEM:

a. All photographic imagery is degraded to some extent by acquisition system limitations and by atmosphere-induced aberrations.

b. Even the smallest aberration in a critical portion of the imagery can be immeasurably expensive in terms of information loss.

c. This loss will be increased by the higher resolution imagery from new collection systems.

d. Efforts to improve the quality of imagery after acquisition are hampered by a lack of basic scientific information.

e. [redacted] under contract for NPIC, has recently demonstrated the feasibility of image restoration through the technique know as spatial filtering. 25X1

f. This project for FY 1967 is a planned specific follow-on phase of a successfully completed FY 1965 contract. Under this new project, the technique of spatial filtering will be further developed and experimentally evaluated.

3. DISCUSSION

a. Origin of Concept.

This follow-on project is part of the Image Analysis Category, one of the 13 major categories forming the NPIC Technical Development Program. The project was initiated in December 1964 by an unsolicited proposal from [redacted] to study the feasibility of restoring imagery by optical processing techniques. On the basis of that proposal, a one-year contract [redacted] was negotiated with [redacted] The contract cost [redacted] and was in effect from 15 May 1965 to 15 May 1966. 25X1 25X1 25X1 25X1

Under the contract, [redacted] investigated the use of coherent light processing to compensate for the distortions introduced [redacted] This technique involves the construction of holograms for use as spatial filters, or masks, to be placed over the degraded imagery being viewed. Work performed to date has shown that this technique is feasible. It is possible to express mathematically the aberrations incurred in 25X1 25X1

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GROUP 1
Excluded from automatic downgrading and declassification

a simple photographic system and in an experimental environment it was possible to construct a spatial filter which corrected certain aberrations. Theoretical studies indicated that other distortions can be corrected in a similar manner.

b. Proposed Program.

The studies and experiments to date have each involved a single type of aberration. The results have indicated that the same techniques can be applied to the complex aberrations found on operational imagery. The next phase, to be carried out under the proposed contract, is intended to validate this theory by the experimental construction and testing of spatial filters.

c. Selection of Contractor.

During the past year, [redacted], has 25X1
exhibited an outstanding ability to understand NPIC problems and has made tremendous progress in an area not previously explored by the intelligence community. [redacted] 25X1
submitted an unsolicited proposal to continue the study and, on the basis of its progress to date and the high quality of the new proposal, the company was chosen for this contract.

d. Program Phasing.

As shown graphically on the attached TAB C, there will be major milestones at the end of two, six, and twelve months in this one-year project. At each of those points, NPIC technical monitors and Agency decision makers will be able to decide whether the goals of the project are being met and whether further efforts should be abandoned, redirected, or continued as planned. An estimate of the three-year effort necessary to make this technique operational is illustrated in TAB D.

e. Coordination.

There has been thorough coordination of this project with DD&ST through discussions with [redacted] of ORD. In 25X1
addition, there is similar coordination with the Air Force the only other government component known to be sponsoring research in this field.

f. Alternatives.

This project is similar in ultimate purpose to the Digital Image Restoration Project we are supporting at [redacted] 25X1
However, there are fundamental differences in the basic approach and the potential applications in each case. The [redacted] 25X1
project appears to be much closer to the practical application phase.

4. CONCLUSIONS:

The Image Restoration project holds promise of a major breakthrough capable of vastly enhancing the photo interpretation process by making available information which can be obtained through no other means. Results to date have been highly satisfactory and the contractor involved has demonstrated outstanding competence.

5. RECOMMENDATIONS:

It is recommended that approval be granted for a follow-on contract with [redacted] at a funding level of [redacted] for Fiscal Year 1967. 25X1

6. REFERENCES AND ATTACHMENTS:

TAB A. Catalog Form
TAB B. Technical Discussion
TAB C. First Year Program Phasing
TAB D. Three Year Program Phasing

(When Filled In)

R & D CATALOG FORM

DATE: 22 June 1966

1. PROJECT TITLE/CODE NAME
Analog Image Restoration (Spatial Filtering)

2. SHORT PROJECT DESCRIPTION (Follow On)
Correction of the phase of a transfer function of an aberrated image system.

3. CONTRACTOR NAME
[redacted]

4. LOCATION OF CONTRACTOR
[redacted]

25X1

5. CLASS OF CONTRACTOR
Research Laboratory (Commercial)

6. TYPE OF CONTRACT
CPFF

7. FUNDS
FY 1966 $ [redacted]
FY 1967 $
FY 1968 $

8. REQUISITION NO.

9. BUDGET PROJECT NO.
NP-A-3-8315

25X1

10. EFFECTIVE CONTRACT DATE (Begin - end)

11. SECURITY CLASS.
AA-Secret
T-Unclassified
W-Secret

12. RESPONSIBLE DIRECTORATE/OFFICE/PROJECT OFFICER TELEPHONE EXTENSION
DDI/NPIC/P&DS, [redacted]

25X1

13. REQUIREMENT/AUTHORITY
The continuation of this study is essential to increase NPIC's effectiveness in deriving valuable intelligence information from degraded imagery.

14. TYPE OF WORK TO BE DONE
Investigation in the problem areas of optical data processing techniques to compensate for degradations introduced by the low-pass-frequency nature of an optical system.

15. CATEGORIES OF EFFORT

MAJOR CATEGORY	SUB-CATEGORIES
Image Analysis	Optical Systems
	Photographic Enhancement
	Image Restoration

16. END ITEM OR SERVICES FROM THIS CONTRACT/IMPROVEMENT OVER CURRENT SYSTEM, EQUIPMENT, ETC.
Reports on methods and techniques for constructing a filter to correct for amplitude and phase distortions.

17. SUPPORTING OR RELATED CONTRACTS (Agency & Other)/COORDINATION
Thorough coordination with DDS&T has been accomplished through ORD representatives. Coordination with the Air Force to prevent duplication of the following contracts has also been accomplished: [redacted]

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18. DESCRIPTION OF INTELLIGENCE REQUIREMENT AND DETAILED TECHNICAL DESCRIPTION OF PROJECT (Continue on additional page if required)
The purpose of this program is to apply coherent optical processing techniques to the restoration of photographic images. During first year of this program the transfer function of an optical system was determined; then by photographic techniques, the inverse of the function was constructed. The amplitude distortions in a system have been corrected using the inverse filter. Future work will be directed toward correcting phase distortions using similar techniques.

19. APPROVED BY AND DATE

OFFICE	DEPUTY DIRECTOR	DDCI

FORM 2338 SECRET GROUP 1

TECHNICAL DISCUSSION

A brief discussion of the procedure using a hologram as a means of preserving phase information in the image restoration process follows:

Since inverse filtering is a linear process, a linear systems analysis will be assumed here. It is known that an incoherent image abberated by a linear system may be represented as:

$$I_{im}(y) = \int I_{ob}(x)\, s(y - x)\, dx \,, \qquad (1)$$

where

$I_{ob}(x)$ = the object intensity distribution

$s(x)$ = the impulse response of the system.

If the impulse response of the system is symmetric, then its Fourier transform (i.e. the transfer function) is real. This case has been studied and in some instances corrected images have been obtained by constructing inverse filters of real transfer functions. The problem of interest here considers systems in which the impulse response is not symmetric. However, it is important that the impulse be stationary (the shape of the impulse response not change as the point source in the object plane is moved about). This requirement is necessary because we want the same filter to correct the entire photographic frame.

First a hologram of the system transfer function, which in general will be complex, is made. This is done by optically Fourier transforming the transparency containing the impulse response with a coherent beam. The hologram will be made by mixing the transfer function with a plane wave at an angle, α_o, to the axis. This may be done by utilizing Fourier transform holograms as shown in Figure 1. The intensity distribution in the hologram is given by

$$I(x) = |e^{ik\alpha_o x} + \tau(x)|^2 \,, \qquad (2)$$

where $\tau(x)$ denotes the transfer function of interest. Next, a transparency varying as $|1/\tau(x)|^2$ is prepared.

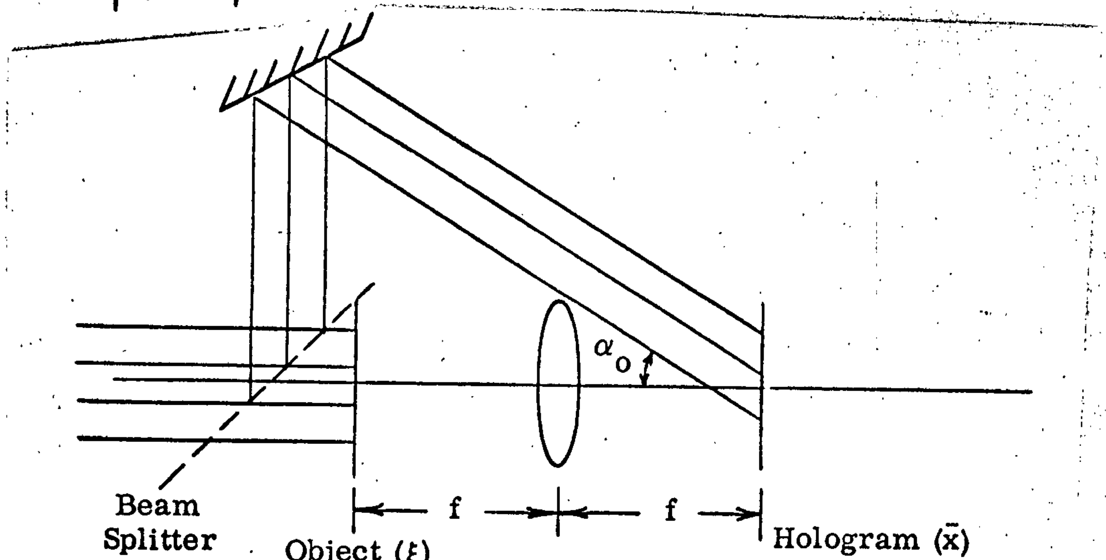

Figure 1 Fourier Transform Holograms

If Eq. (1) is prepared as an optical transparency and then Fourier transformed optically, the aerial image amplitude is described by

$$\tilde{I}_{im}(x) = \tilde{I}_{ob}(x)\, \tau(x) \tag{3}$$

If the hologram transparency of Eq. (2) and the $1/|\tau(x)|^2$ transparency are sandwiched together and placed in the aerial image of Eq. (3), the result is

$$\tilde{I}_{im}(x) = \frac{\tilde{I}_{ob}(x)\, \tau(x)}{\tau^*(x)\, \tau(x)} \left(1 + |\tau(x)|^2 + \tau^* e^{ik\alpha_o x} + \tau e^{-ik\alpha_o x} \right) \tag{4}$$

The third item in Eq. (4) gives

$$\tilde{I}^3_{im}(x) = \tilde{I}_{ob}(x)\, e^{ik\alpha_o x} , \tag{5}$$

which upon Fourier transformation by a lens of focal length f gives

$$I^3_{im}(y) = I_{ob}\left(\frac{y}{\lambda f} - \frac{\alpha_o}{\lambda} \right) , \tag{6}$$

which is just the corrected image centered at $y = \alpha_o f$. The other terms in Eq. (4) are physically separated in space from the corrected term described by Eq. (6) if α_o is made large enough. Although these terms are further aberrated by the hologram filter, this does not matter since they appear at different points in space. Thus it appears that the Hologram technique is one very feasible way to filter out a complex transfer function.

TAB C
15 JUNE 1966

IMAGE RESTORATION
(FIRST-YEAR PROGRAM)