PRINCETON UNIVERSITY OBSERVATORY
Princeton, New Jersey

FINAL REPORT

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APPLICATION OF DIGITAL COMPUTER TECHNIQUES TO RECTIFICATION AND ENHANCEMENT OF ASTRONOMICAL IMAGES

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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PERSONNEL

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FISCAL STATUS

Value of Contract	$195,700
Expenditures as of December 31, 1973	195,700
BALANCE	-0-

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I. IMAGE PROCESSING OF STRATOSCOPE DATA

Princeton's Image Processing Program was developed in order to analyze the high resolution images obtained by the balloon borne 36" diameter Stratoscope II telescope. A variety of software and hardware was developed which permitted the Stratoscope images to be displayed in the most effective manner. Equally important, it allowed quantitative analysis of the data.

The first significant phase of the program involved adapting the JPL's VICAR image processing program to Princeton computers. Early in 1969, the VICAR Program was adapted to a 360/50 computer. This allowed us to register and stack pictures in the computer, thereby reducing the "grain noise" substantially. It allowed us to deconvolve (sharpen) the pictures to the extent allowed by the noise.

Concurrently with this initial software development, a film recording device was developed which was capable of converting numerical data from the computer into photographic images. This apparatus also converted the analog output of TV cameras in a digital form on magnetic tape which was compatible with computer image processing. This vital equipment was developed by J. Lowrance and P. Zucchino.

Conversion of Stratoscope images to digital form required careful microdensitometry. After an initial attempt to have it done commercially, we performed the microdensitometry at the Sacramento Peak Solar Observatory.

The first test of the image processing system was performed on four Stratoscope I images of sunspots which were obtained during flight 1959D. The results were published in the proceedings of a symposium on the Astronomical Use of Television-Type Image Sensors (NASA SP-256) held at Princeton on May 20-21, 1970. (The symposium was partially supported by this grant.)

In this paper by R. E. Danielson and M. G. Tomasko (entitled Image Processing of Stratoscope Photographs, pp. 199-205), it was shown that a deconvolved image of the average of the four individual sunspot pictures (formed by stacking them) contained more detailed structure than was apparent on any of the individual photographs.

On March 26-27, 1970, a flight of Stratoscope II (Flight No. 7) obtained high resolution images of Uranus, Jupiter, and its satellite, Io. Photographs of stars revealed that the Stratoscope instrumental profile was not circularly symmetric. Consequently, the analysis of these images required the development of computer programs for asymmetric deconvolution. Concurrently with this development, the modified VICAR program was adapted for use on Princeton's main computer, an IBM 360/91.

The key application of the Image Processing System was in the analysis of the image of Uranus. The analysis has been published (Astrophysical Journal 178, 887-899 (1972). In brief, a composite image of Uranus was produced from 17 photographs. No surface features were evident, but a pronounced limb darkening was measured and compared with theoretical models.

Similar processing was performed on Stratoscope II photographs of Jupiter and Io. Results of the latter may be found in Sky and Telescope 42, 10-11, July 1971.

During Flight No. 8 of Stratoscope II (Sept. 9-10, 1971), high resolution images were obtained of the nucleus of M31 (the Andromeda Galaxy). The results of processing these images will appear in the November 1974 issue of the Astrophysical Journal under the title "The Nucleus of M31". The key result of this analysis is that the nucleus appears to be a separate feature from the central bulge of the Andromeda galaxy. These photographs showed the star-like nucleus to have a "diameter" of about 3 light years (1 parsec).

II. OTHER APPLICATIONS OF THE IMAGE PROCESSING FACILITIES

Three other uses were made of the Image Processing facilities. The first was calculating the shape of the point-spread functions which would be formed by an optical system having specified amounts of coma, astigmatism, or other aberrations. From the specified aberrations, the corresponding pupil functions were calculated. The desired point-spread function was calculated as the square of the Fourier Transform of the pupil function. The point-spread function was displayed photographically by means of the facsimile scanner. These point-spread functions were used in the field as an aid in optically aligning the Stratoscope II instrument.

A second use of the Image Processing Facility was to display radio astronomical data in visual form. In collaboration with radio astronomers, Dr. E. B. Jenkins has converted radio astronomical scans into visual pictures. An example of this work may be found in an article by C. Heiles in Galactic Radio Astronomy edited by F. J. Kerr (the proceedings of IAU Symposium No. 60). This article contains a picture of the 21 cm emission from neutral hydrogen in our galaxy. A spectacular color version of this picture has been produced which uses different hues to discriminate radial velocities and brightness to show relative hydrogen column densities. This picture, along with others which show the distribution of dust and low-frequency radio emission in our galaxy, is being prepared for publication. Another example may be found in the thesis of A. H. Rots: The Distribution and Kinematics of Neutral Hydrogen in the Spiral Galaxy M81; where a radio image of M81 obtained by the Westerbork

Synthesis Radio Telescope is shown. Similar work on M101 (in collaboration with R. Allen) is in preparation.

A third use was in analyzing the results of rocket data. Lyman α images obtained of comet Tago-Sato-Kosaka were computer processed. When displayed, they suggested that the comet had a bright core in emission. This work was published by Jenkins and Wingert (Ap.J. 174, 697, 1972). Another example of image processing techniques applied to rocket data may be found in a paper by Jenkins, Morton, and York (Ap.J. 193, Nov. 15, 1974 issue in press).

III. IMAGE PROCESSING OF INTEGRATING TELEVISION IMAGES

One of the key motivations for the Princeton Image Processing program was the analysis of Integrating TV images. In preparation for using Integrating TV detectors on the LST and other orbiting telescopes, a series of observations was made on large ground-based telescopes by D.C. Morton and P. Crane. Vital to this work was the analog to digital equipment which converted the analog TV output to a format suitable for digital computer processing. Equally vital was the ability to photographically display the data with the facsimile scanner.

As a result of several observing trips to the Hale Observatories, D.C. Morton and his colleagues obtained a series of high resolution spectra of quasi-stellar objects (QSO's) and of galaxies. He and his associates analyzed the data using the image processing facilities. A list of publications resulting from these observations is given below:

1) "The Spectrum of the Quasi-Stellar Object PHL 957", by J.L. Lowrance, D.C. Morton, P. Zucchino, J.B. Oke, and M. Schmidt. Ap.J. 171, 233 (1972).

2) "Absorption-Line Profiles in the Quasi-Stellar Object PHL 957", by D.C. Morton and W.A. Morton, Ap.J. 174, 237 (1972).

3) "Velocity Dispersions in Galaxies I. The E7 Galaxy NGC 7332", by D.C. Morton and R.A. Chevalier, Ap.J. 174, 489 (1972).

4) "Absorption Lines in the Spectrum of the Quasar Ton 1530", by W.A. Morton and D.C. Morton, Ap.J. 178, 607 (1972).

5) "Velocity Dispersions in Galaxies II. The Ellipticals NGC 1889, 3115, 4473, and 4494", by D.C. Morton and R.A. Chevalier, Ap.J. 179, 55 (1973).

6) "Velocity Dispersions in Galaxies III. The Nucleus of M31", by D.C. Morton and T.X. Thuan, Ap.J. 180, 705 (1973).

7) "Absorption Lines in the Spectrum of the Quasar Markarian 132", by D.C. Morton and D.O. Richstone, Ap.J. 184, 65 (1973).

8) "Absorption-Line Spectra of the Quasi-Stellar Object 957", by D.W. Wingert, B.A.A.S. 5, (1973) and Ap.J. in Press (1975).

9) "Velocity Dispersions in Galaxies IV. The Nucleus of NGC 1068", by D.O. Richstone and D.C. Morton, submitted to Ap.J. (1974).

10) "Rotation in the Nuclei of M31 and M32", by R.S. Pariseau, Princeton University Senior Thesis (1974).

Dr. P. Crane of the Princeton University Department of Physics and his colleagues have used the SEC-Vidicon TV system to obtain photometric measurements of galaxies and the sky background. They have also studied the properties of the

SEC Vidicon and the Silicon Vidicon cameras. All of these studies made use of the image processing facilities. Details may be found in the following publications:

1) Intergalactic Dust: A New Upper Limit: Crane and Hoffman, Ap.J. 186, 787 (1973).

2) TV Photometry of Emission Lines in the Crab Nebula: Davidson, Crane and Chinicarini, A.J. 79, 791 (1974).

3) The SEC Vidicon as a Photometer: P. Crane in Proceedings of the Conference on Astronomical Observations with Television Type Sensors, edited by J.W. Glaspey and G.A.H. Walker (The Institute of Astronomy and Space Science UBC Canada, pp. 391).

4) Characteristics of the Silicon Diode Vidicon: Crane and Davis, PASP (in press).

5) Surface Photometry of Galaxies I. The SBO NGC 2950; P. Crane (submitted to A.J.).

6) Television Surface Photometry of the Edge-on Spiral Galaxies NGC 3987 and NGC 5907; M. Davis (submitted to A.J.).

IV. THE FUTURE OF THE IMAGE PROCESSING FACILITY AT PRINCETON

The motivation for developing the image processing facility was the need to efficiently analyze high resolution images obtained by Stratoscope II and, eventually, by diffraction limited orbiting telescopes. However, the untimely cancellation of the Stratoscope II program (at the time it had become an effective observing instrument) plus the fruitless attempt to design a Stratoscope III instrument to an unrealistically low cost eliminated the key application of the image processing facility. Furthermore, the strategy of cancelling the OAO program and the abandonment of promising ASTRA studies in favor of a diffraction limited 3-meter LST has led to the situation where the first images from an orbiting telescope will not be available for another 5-10 years.

Naturally, one impact of the above developments was the loss of the manpower needed to carry forward the program. Sensing the trend, Dr. Karl Davis left the Image Processing Program to take a more promising position. Consequently, the much needed program for photometrically testing and calibrating Integrating TV cameras for space applications which he had begun was not continued. Under the conditions, it was not possible to obtain a suitable successor to continue the work.

A second impact concerned the VICAR computer program. The cessation of the Stratoscope data reduced the use of this program to the point that it could not be easily maintained. Since VICAR made efficient use of the 360/91 operating system, each change in the Operating System generally required some change in VICAR to make it compatible. While this is practical at a sufficiently high level of usage, it is impractical if the usage is low. At the present time, the VICAR program has been stored on magnetic tape in such a fashion that a skilled programmer could resurrect it if it were desirable to do so at some future date.

In the near future, only the facsimile scanner is likely to receive substantial use. TV cameras continue to be employed for research on ground-based telescopes and developed for future space applications. Indeed, the recent development of a 70 mm camera target will require expansion of the scanner electronics to accommodate the larger number of pixels per line. There will probably be continued use of the scanner for radio astronomy images. Photometric testing of TV cameras is continuing under NAS5-20069.