NOAA Technical Memorandum NOS CGS 3

OVERVIEW OF THE INTEGRATED DIGITAL PHOTOGRAMMETRIC FACILITY

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U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Ocean Service / Office of Charting and Geodetic Services

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UNITED STATES DEPARTMENT OF COMMERCE
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National Oceanic and Atmospheric Administration
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PREFACE

This document highlights the broad capabilities and unique design features that motivated development of the Integrated Digital Photogrammetric Facility and assured its longevity. Although a primer on photogrammetry and cartography is included, it is expected that most readers understand basic photogrammetry. Mathematical and computer science details are not included.

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ABSTRACT. The Integrated Digital Photogrammetric Facility (IDPF) software package drives networked stereoviewers that share a common data base. IDPF's longevity is assured by its independence from specific stereoviewer hardware, easily modified application software, and its integration with standard National Ocean Service (NOS) map projection, aerotriangulation, and camera calibration software packages. Sophisticated computer control of the operational environment minimizes data entry errors through online error checking, system supplied data, and formatted screens.

1. INTRODUCTION

The Integrated Digital Photogrammetric Facility (IDPF) is a photogrammetric software package that drives analytical stereoviewers and employs computer graphics and relational data base management technologies. IDPF accepts any format photography, and performs diverse jobs such as coastal mapping, airport mapping, photobathymetry (underwater mapping in clear water), and close-range (nontopographic) photogrammetry. Graphic superimposition allows compiled map data to be viewed against the source imagery. IDPF was developed by the Photogrammetric Technology Programs Section in the Nautical Charting Research and Development Laboratory (NCRDL) and is integrated with other NOS general purpose photogrammetric packages. IDPF's development, which began in 1984, led to an operational system in 1987. The system's initial capabilities, which were limited to aerotriangulation, were expanded to include a complete digital compilation package in 1989. The final developmental phase will be completed in mid-1991, and will involve data base management enhancements and additional application programs.

IDPF is unique in its independence from specific stereoviewer hardware and in its ability to compile continuous digital data across stereomodel and map sheet boundaries (sec. 3.4). Hardware independence, which extends beyond the stereoviewer to various peripherals, allows the system to survive the rapidly changing hardware market and benefit from the incorporation of improved technology. IDPF application software is driven by full screen editors. User input errors are minimized by online error checking, system supplied data, and formatted screens.

IDPF stereoviewers and their peripherals form individual photogrammetric workstations (PWS's) which are linked as nodes in a network and share a common data base. Figure 1 graphically depicts the current IDPF configuration, consisting of two production networks and a research network. This configuration contains five PWS's, two at Rockville, Md., and three at Norfolk, Va. The PWS stereoviewers, Ottico Meccanica Italiana Corporation of America model No. AS-11PA-3, have 9- by 18-inch photo transport stages. Software is implemented on a Digital Equipment Corporation VMS operating system.

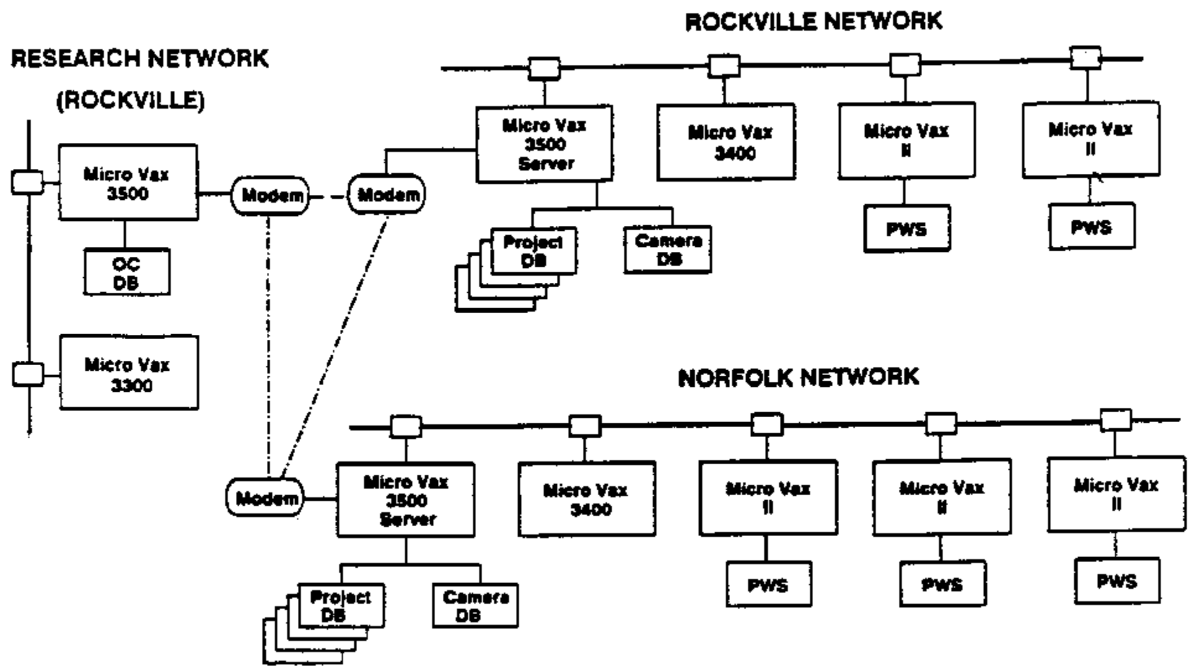

Figure 1.--IDPF system configuration.

1.1 Motivation for Development

IDPF was developed for three basic reasons. First, NOAA needed to replace an aging photogrammetric infrastructure, which used less efficient analog technology, with a new versatile digital system. Second, the new system would support internal needs for digital photogrammetric data, e.g., the Hydrographic Data Acquisition and Processing System and Aeronautical Obstruction Program. Third, digital photogrammetric data would be provided to the Automated Nautical Charting System II which will provide NOS' digital products to a broad spectrum of users.

1.2 Primer on Photogrammetry and Cartography

Photogrammetry is the science of deducing physical dimensions of objects from measurements on images of the objects (NOAA 1986). Land surface is the traditional subject of measurement. Measurement is remote (indirect) which is usually from aerial photography. Because the photogrammetric camera is like an airborne surveyor's thedolite, photogrammetry is often referred to as "aerial surveying. Interpreted land features with geographic coordinates are compiled from aerial photography by an operator on a stereoplotter (stereoviewer). Coordinates defining named or coded features are stored in computer files and can be viewed on a graphics terminal or plotted in hard copy form. To obtain ground coordinates from measurements on aerial photographs, the transformation between the ground and photocoordinate system must be known. To compute this transformation, surveyed ground control points must be visible (measurable) on overlapping photographs. The mathematical procedure for computing the transformation parameters is known as analytical aerotriangulation. Conventional photogrammetry produces map data in paper or digital form. Figure 2 depicts the stages of a conventional photogrammetric project. However, within the last decade, digital imagery obtained from sensors such as radar, satellites, and medical imaging devices has been used to

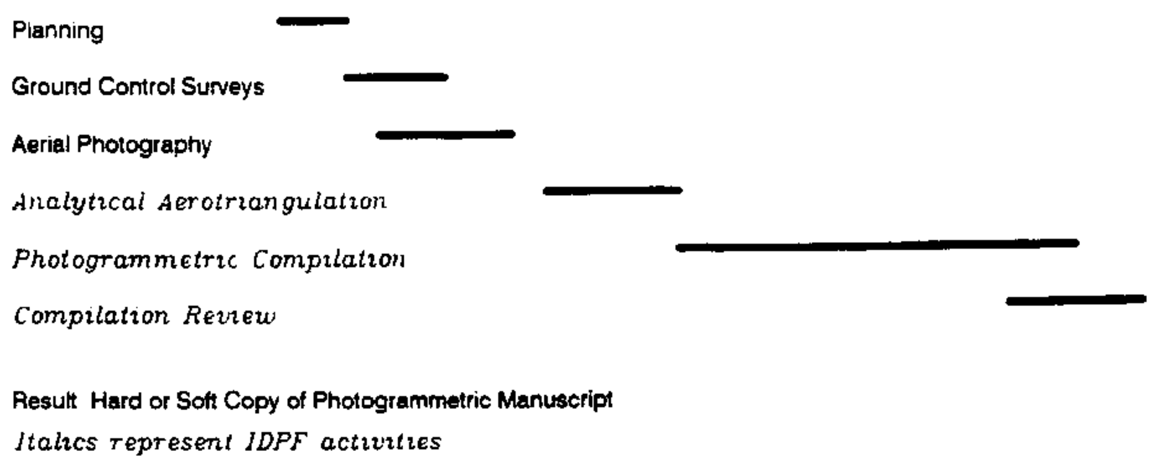

Figure 2.--Stages of a photogrammetric project.

support applications ranging from continent-wide reconnaissance to mapping the terrain of a tooth. Imagery is recorded in computer readable form where it can be analyzed by machine, selectively displayed, and manipulated.

Cartography, on the other hand, is a science that visually portrays geographic and statistical data. Some map data may portray original photogrammetric surveys. To satisfy the constraints of visual portrayal, map features are symbolized, generalized, and sometimes displaced. These manipulations create a degradation in positional accuracy. Therefore, the positional accuracy of photogrammetric or survey source data is not fully recoverable from a cartographic product.

2. SYSTEM ARCHITECTURE

IDPF software operates within a group of general purpose computers connected in a network. Some of the computers in the network serve as controllers to attached PWS's. The PWS consists of four devices which are viewed collectively as a single node in the computer network (fig. 3).

- o A standard computer terminal serving as a computer control console.
- o A graphics terminal for map display and interactive editing. The terminal can be any available commercial computer graphics terminal.
- o One or two graphics terminals display compiled map data which is injected into the optics and superimposed on the source imagery. A PWS can function without superimposition if it is not required.
- o A photogrammetric stereoviewer with two image transport stages (platforms) and a variety of controls necessary for performing typical photogrammetric operations.

Residing on the same network are a number of data bases. One contains the complete history of camera calibrations for the mapping institution, and the others contain individual project data. Both the camera calibration data base and project data bases are shared among all PWS's. The coordination of data base sharing is one of the primary functions performed by the network.

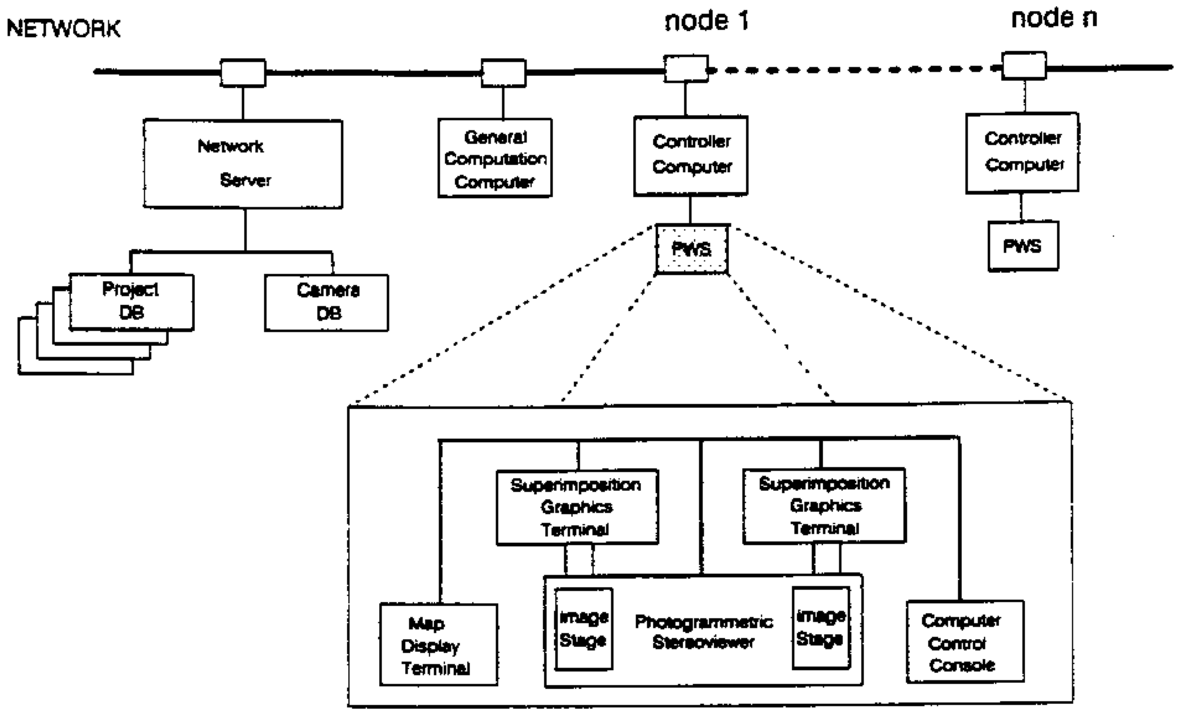

Figure 3.--IDPF system architecture.

3. SPECIAL DESIGN FEATURES

IDPF's longevity as an efficient system is assured by design features which provide (1) a standard interface, (2) standard and specialized software that can be easily modified, (3) sophisticated computer control of the operating environment, (4) the ability to compile a "seamless" map with no discontinuities across stereomodel map junctures, and (5) integration with other NOS photogrammetric and cartographic packages.

3.1 Stereoviewer Standard Interface

The interfaces providing communication between the control computer and PWS graphics terminals are supplied by the vendors of the graphics terminals. However, the situation with respect to the stereoviewer interface is quite different. The size of the photogrammetric hardware market worldwide is too small to provide vendors the incentive to promote standardized stereoviewer interfaces. The lack of such standards makes it difficult to mix stereoviewer hardware from various manufacturers into a single production environment, burdening the task with high risk and uncontrolled cost. Therefore, a primary goal of IDPF design was to develop a standard interface, thereby greatly reducing stereoviewer hardware dependence.

The IDPF standard interface has two main components, the Virtual Stereoviewer and the Mapper (fig. 4). The Virtual Stereoviewer is an idealized stereoviewer with extensive capabilities. The capabilities of all existing and anticipated future stereoviewers can be represented by the Virtual Stereoviewer. The components of the Virtual Stereoviewer are as follows:

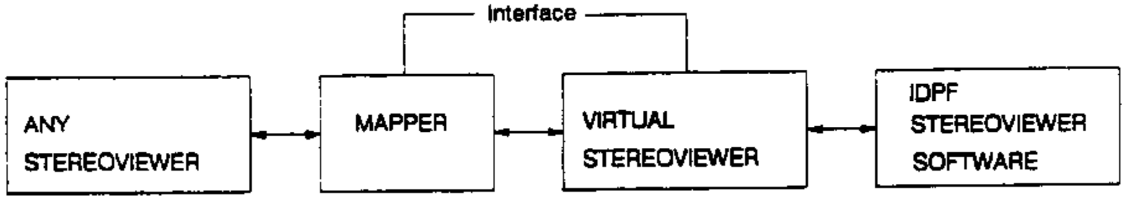

Figure 4.--The stereoviewer interface.

- o Two image transport stages.
- o A bank of dials controlling map viewing.
- o A control panel of binary switches.
- o An audible signal device.

The Mapper is a set of tables which are required to map all computer controlled facilities for specific stereoviewer hardware into the Virtual Stereoviewer. The Mapper is therefore hardware specific. It is the only software development that is required for IDPF to interface to any stereoviewer which complies with the standards.

3.2 Standard and Specialized Software

The control computer for a PWS drives and coordinates its four components (sec. 3.1). The PWS control computer simultaneously executes several coordinated processes. Real-time routines cycle at 50 to 60 times per second to maintain the exact relationship between the ground and image coordinate systems. The math model serving this transformation can vary to accommodate any photogrammetric sensor (frame camera, panoramic camera, radar). Other real time functions compute transformations between the graphic map display and the reference coordinate system.

IDPF's modular software can be modified to accommodate future software applications and changes. While photogrammetric math models and algorithms are rigorous and standardized, optional refined models are provided to compensate for film distortions due to unpredictable and flight-specific conditions (sec. 5.1).

3.3 Automated Control of the Operating Environment

Operational efficiency is improved by minimizing operator data input errors. This is done by reducing operator input, and enforcing online quality control algorithms. Examples of online quality controls include: (1) interactive formatted data entry screens, (2) preliminary project data bases that guide and supply data to successive instrument functions, (3) suites of selectable and system imposed error checking for image point mensuration, and (4) graphic superimposition and feature traceback in compilation.

3.3.1 Data Entry by Menu-Driven Formatted Screens

IDPF instrument and data base functions are driven by nested menus and formatted full-screen editors (fig. 5). The screens enforce data format, supply lists of existing data values, and minimize operator error. The menus enhance smooth

```
PROJECT  CM8106    - ISLA DE VIEQUES P.R. PHOTOBATHYMETRY
+------------------------------------------------------------------------------+
||   NOAA / NOS          * editing CONTROL POINT record *      IDPF V1.0  1/90 ||
|+----------------X:PROD------26-DEC-89----15:45:55-------------JOHNSTONE-----+|
|                                                                              |
|action performed by pressing PF3 key  RETRIEVE record from file              |
|Control Point ID (key)     new id                                             |
|                                                                              |
|+-------------------------- Control Point Position -------------------------+|
||Horizontal in  DMS                          |  Vertical in  meters         ||
||   -653432.858000000        180648.693000000 |           0.434000000       ||
||Reference System  Geographic                                               ||
||                                                                           ||
|+----- select new System, Zone or Units for control point position?  NO ----+|
|                                                                              |
|Type of Control  pass point                                                   |
+------------------------------------------------------------------------------+
```

Figure 5.--Formatted screen for geodetic control point input.

navigation through operations. The screens contain modifiable fields and fixed informational fields. A field is a location on the screen where alphanumeric information is displayed, input, or selected from a computer-generated list called an item list. If a data field has an item list, the item list can be browsed sequentially, searched for a particular value, or viewed in its entirety. Most of the screens and menus are generated by the Screen Data Editor (Keltz 1988), a multipurpose utility. All instrument and data base operations are described in the IDPF User's Guide (Snyder 1990). A revised guide will be available in February 1991.

3.3.2 Project Data Base

The project data base is the heart of an IDPF mapping project. A preliminary project data base is created to guide aerotriangulation functions. It contains project wide parameters such as datum definition and approximate photo exposure station positions and attitude angles. The system assists the user in generating redundant data base information. For example, estimates of photo exposure station positions can be automatically generated for any length strip of photography, based on data for the first and last photos. These photo-data are used by the system to aid the operator in locating identical points on overlapping photos during mensuration.

3.3.3 Image Point Mensuration Controls

Accurate image point measurement is a fundamental photogrammetric requirement. Image points relate photocoordinate systems to each other and the ground system, and along with survey control points are the primary input to aerotriangulation. IDPF uses automated image point transfer (with automatic numbering) to eliminate the need for destructive and time-consuming image point drilling (marking). Instead of physical photo marking, photocoordinates are stored by photo with a point identifier. In addition, IDPF provides a unique set of powerful yet flexible facilities for online quality control of image point measurement. The following examples illustrate each class of quality control facilities: those that can be tailored by a user or project manager, those that are imposed by the system, and those that are optional to the user.

Automatic evaluation of image point identifiers is a system-imposed check. If the user enters a point identifier that already exists within the current project, the system issues a warning but allows redundant naming. If the selected point identification exists on the current stereomodel, the system prevents its repeated use and provides the operator with an error message.

The Define Default Measuring Environment (DDME) function is an optional and flexible user defined function. DDME sets procedures and measurement precision tolerance values that control image point and fiducial measurement. Values can be tailored to suit any level of rigor. Figure 6 shows the DDME function setup screen.

The Single Model Triangulation (SMT) function is an optional but useful tool for detecting blunders in image point measurement. This function can be exercised after measuring all points in a stereomodel. Large residuals expose blunders that can be corrected before proceeding to the next model.

3.3.4 Graphic Superimposition and Compiled Feature Traceback

Superimposition injects compiled map graphics into the optical train in such a manner that the graphics appear "superimposed" on the photos. Superimposition serves as a "completeness" check in compilation. Gaps and missing line work can be spotted and corrected before leaving the stereomodel. Also during compilation, the floating dot (measuring mark) can be made to retrace the path of a compiled feature. Retrace is an "accuracy" check.

3.4 Seamless Map

A common problem in photogrammetric compilation is that detail compiled within stereomodels and between adjacent maps does not precisely juncture with adjoining stereomodels and maps. A common solution is to rubbersheet or rework detail to force a fit. Such a solution adds an unknown and unrecoverable amount of error into the product. IDPF eliminates this problem by retaining the current measuring mark geographic position upon a change in stereomodel or map, providing an overlap exists between the old and the new. When switching stereomodels, the feature being compiled is kept open for digital recording so that it is also continuous at the data base level. Mathematical consistency between instrument setting parameters exists since all parameters are computed in a common block adjustment. The result is a seamless map that extends throughout the project area.

3.5 Integration With Standard NOS Photogrammetric and Cartographic Packages

IDPF incorporates several widely used photogrammetric packages. The General Integrated ANalytical Triangulation (GIANT) Program (Elassal 1987) performs the analytical aerotriangulation for IDPF. In aerotriangulation, the ground coordinates of all measured image points and the position and orientation of every camera in a block of photography are determined and written into the project data base. Camera station positions and orientations are automatically transformed into PWS instrument settings for map compilation. During compilation and other functions, geographic positions can be converted to any of 20 common map projections using the General Cartographic Transformation, Version II, Package (Elassal 1987). IDPF is also being interfaced to the NOS camera calibration system (Malhotra 1990). The interface will format and store calibration data directly into the IDPF camera calibration data base.

```
|   NOAA / NOS     * DEFINE DEFAULT MEASURING ENVIRONMENT *  IDPF V1.0  1/90 |
+--   CM8106    --X:PROD------22-DEC-89---13:26:28----- PWS1 ---JOHNSTONE-----+
+-----------------------------------------------------------------------------+
||                          STAGE MEASURING ENVIRONMENT                      ||
|+---------------------------------------------------------------------------+|
|----------------------------- FOR ALL STAGES---------------------------------|
|                                                                             |
|Automatic Repeat of Bad Measurement        YES                               |
|Automatic Force of a Measurement           YES                               |
|Automatic Full Set of Repeat Pointings     YES                               |
|Automatic Backoff of Pointing              NO                                |
|Maximum Number of Repeat Points/Readings    3                                |
|                                                                             |
|--------- FOR STAGE   LEFT_STAGE  --- SELECTED RECORD  none        ----------|
|                                                                             |
|Maximum Allowable Deviation from Mean X    5                                 |
|Maximum Allowable Deviation from Mean Y    5                                 |
|                                                                             |
|                                                                             |
+-----------------------------------------------------------------------------+
```

Figure 6.--Define default measuring environment function screen.

4. SYSTEM CAPABILITIES AND EXPERIENCE

IDPF's exceptional capabilities include an atmospheric refraction model that includes water refraction indices (making photobathymetry possible); close-range (nontopographic) photogrammetry; the ability to use various imagery types; camera self-calibration; and automatic facilities to handle a multitude of measurement units.

Special projects have been completed on the IDPF PWS in the areas of photobathymetry, close-range photogrammetry, and aerotriangulation using photography obtained from the Large Format Camera NASA Space Shuttle Mission STS-41G in October 1984.

In one instance, a close-range photogrammetry project was completed for the Department of Navy, David Taylor Research Center (DTRC). IDPF was used to capture a grid of digital 3-dimensional data covering the wake generated by miniature ship models being towed along the DTRC towing tank (fig. 7). Grid points were spaced every 3 inches, covering more than 7000 points per stereopair. Stereopairs were captured by Hassalblad MK-70 cameras mounted 9.1 m above the water. A collapsible surveyed target grid provided the reference coordinate system. Measurement precision was approximately 1.37 mm in elevation. The resulting wave-height data were used to optimize ship hull designs.

5. RECENT ENHANCEMENTS

IDPF is designed to serve NOAA's photogrammetric needs during the 1990s and beyond. Therefore, the system must be enhanced periodically to improve both functional capabilities and ease of maintenance.

5.1 Improved Photogrammetric Modeling

During flight, there are various unmodeled and unpredictable distortions that can affect the photography. Generally these are due to varying in-flight environmental changes which affect film and camera geometric stability, creating a

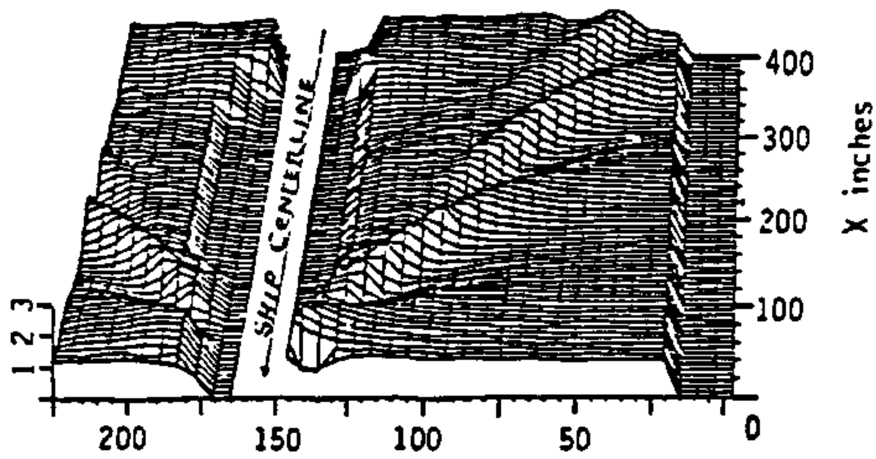

Figure 7.--Photogrammetrically derived wave heights.

departure from calibrated (ideal) conditions. The accepted solution to this problem is to add carefully selected parameters to the standard mathematical model to compensate for these errors. These parameters, when properly implemented and statistically verified, can significantly improve the quality of photogrammetrically determined ground coordinates. GIANT has been modified to include these parameters. In doing so, it is now possible to perform camera self calibration (given the proper geodetic control scheme and other rigorous controls). Self-calibration refers to the determination of camera geometry through aerotriangulation in which camera parameters are considered unknown.

5.2 Global Positioning System Application

Kinematic (airborne) Global Positioning System (GPS) technology can provide observations of camera station position to decimeter accuracy. Using kinematic GPS, dependence on ground-based control is minimized or eliminated. In remote locations, there is often no ground-based control available to support photogrammetric work. Use of GPS-controlled photography will be particularly valuable in these instances. GIANT has been modified to include GPS positions as weighted observations. The operator of IDPF merely has to set a switch to identify the project as GPS-controlled.

6. FUTURE PROJECTS

A future IDPF requirement could be linked to a proposed periodic coverage of the Nation's coast by wide-angle aerial mapping photography. Controlled photography could be obtained by kinematic GPS and provide accurate information on coastal change. Such a photographic data base would support a variety of NOAA operations (in addition to chart making) and a plethora of Federal, State, and regional programs concerning fisheries (delineation of sea grasses supporting fish productivity), adverse human impact (wetlands delineation), and natural physical hazards modeling (storm surge prediction, shoreline erosion, and sediment transport). Acquired photography supporting such a data base, including that obtained from other organizations, would be immediately triangulated so that stereomodels could be set at any time. From stereomodels, precise measurements could be provided for interpreted coastal features and phenomena as needed.

IDPF might also be used to support selected multipurpose cadastre/land information system projects. The degree to which IDPF can be applied to these efforts will depend on the availability of NOS technology for economical and efficient cadastre map data handling. Kinematic GPS could provide geodetic control for photogrammetric triangulation, providing a dense control net upon which cadastral data layers would be compiled.

7. CONCLUSIONS

Given the rapid advances in stereoviewer hardware, imaging devices, and photogrammetric requirements, a major goal in IDPF development was to build a flexible system for long-term use. IDPF's longevity is assured by its independence from specific stereoviewer hardware, easily modified application software, and integration with standard NOS map projection, aerotriangulation, and camera calibration software packages. Sophisticated computer control of the operational environment minimizes data entry errors through online error checking, system supplied data, and formatted screens. The network environment allows several users to access the same project data base simultaneously. As a result, NOS is capable of providing quality photogrammetric data in support of a wide-range of needs.

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