FRONTISPIECE. The Qasco SD-4 Stereodigitiser

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The Qasco SD-4

A description of and the logic behind the development of a new analytical stereoplotter.

(*Abstract on next page*)

INTRODUCTION

THE QASCO SD-4 is an analytical photogrammetric instrument which can be used as the "heart" of an analytical stereoplotter system, or simply used as a "stereodigitizer" to extract *X, Y, Z* coordinates from a stereopair of photographs. It has been designed as a simple, compact, low cost unit, with a least count of 6 micrometres, capable of performing most photogrammetric operations.

BASIC DESIGN CONCEPTS

GENERAL COMMENTS

An analytical instrument is not subject to many of the design constraints imposed on mechanical analog plotters, and the designer is free to locate elements such as photo carriers in positions favorable for optimum mechanical and optical design. Therefore, rather than simply adapt a general layout similar to that used in most mechanical analog instruments, one can first specify basic design and performance criteria, then consider the necessary components and their layout.

The prime aim of the SD-4 project was to produce an effective, low-cost unit suitable for most photogrammetric operations, and to meet this aim it was essential to use "off the shelf" components wherever possible. Items such as motors, drive screws, guide rails, bearings, optical components, etc., would be selected from standard units which were readily available from several alternative suppliers.

It is important that any new instrument be designed to have a reliability approaching that of existing mechanical analog equipment. This requires that all components must have proven reli-

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ABSTRACT: *A new analytical stereoplotter is described together with the logic behind its design. The unit can handle any photography up to standard 9 by 9 inches in size, yet is portable and can operate either as a computer terminal or as a separate system. Accuracy of measurement at the photo scale is better than 10 micrometres, and the drive system utilizes stepping motors and recirculating ball screws under microprocessor control. Final accuracy is achieved by means of corrections applied by the microprocessor from a table stored after an initial calibration has been performed.*

ability in other industrial applications before being considered.

The instrument itself should be as simple as possible with a minimum number of moving parts. This not only reduces the initial cost, but also simplifies service and routine maintenance of the equipment. Each moving component should be positioned by a motor directly coupled to a system acting on the center of mass of the component. Moving parts should be as light as possible in order to reduce wear and tear and minimize power requirements of the drive system.

Analytical plotters can be used in many photogrammetric operations outside of the fields of mapping from aerial photographs. Because in many instances the operator may not be a skilled photogrammetrist, the computer systems controlling the instrument should minimize the work to be performed by the operator, particularly in the initial setting up and orientation phases.

The instrument should be compact, preferably about the size of a computer CRT, and it should be able to operate in an environment without special atmospheric control. It should be sufficiently portable to be used in the site office of a large construction project, or in surveying or mining camps, or be moved around in an office or research laboratory.

The controls should be simple, there should be few special switches, and orientation should be carried out interacting with detailed "prompts" being issued from a CRT. Because many photogrammetric operators are not used to working directly with computer systems, considerable care is necessary in the design of software. The system should be "friendly" and allow the operator to repeat any step or steps, and if an invalid response is given to any request, the system should simply repeat the request in order to allow the operator a second chance.

OPTICAL CHAIN AND PHOTO CARRIER ASSEMBLY

In order to scan a stereopair of photographs, one can have either fixed optics and move the photographs, or the photographs can be fixed and parts of the optical chain can be moved.

If the photographs are fixed, additional lenses are needed in the optical system to correct for the variation in distance between the eyepiece and different parts of the photo image. However, there can be a significant decrease in the size and complexity of the guidance system because each scanning head can be of small mass and the range of movement is contained inside the edges of the photography.

If the optics are fixed and the photographs are moved, the optics can be simplified, but the support system for the photos has to be more massive in order to prevent distortion as they are moved, and the guide rails for each photo carrier have to be at least twice the width of the photographs. Analytical plotters which have fixed optics are generally as large as their mechanical analog counterparts, whereas those with fixed plates are more compact.

By incorporating a Kappa adjustment in one of the photo holder assemblies, it becomes unnecessary to include a dove prism in the optics in order to achieve stereoscopic vision. Most operators can easily fuse an image where the rotation between photos in a stereopair is less than two degrees; therefore, there seems little justification for the inclusion of a power operated dove prism assembly with its associated costs and tax on light transmission.

These factors suggest that, in order to have a simple compact instrument, the photo carriers should be fixed and a Kappa adjustment built into one of these units.

The y-parallax component in most stereoscopic photographs is less than 5 mm, and it is only in special cases such as terrestrial work where a large base swing has to be adopted that this value is exceeded. Therefore, a fixed plate system with a common y drive can be developed if provision is made to accommodate small amounts of y-parallax.

DRIVE SYSTEM

There are two main approaches to this problem:

(1) Feed-back or closed loop systems are used in most of the more precise analytical plotters. In principal, the computer determines the distance to be traveled and generates signals to electronic logic which regulates current to each motor. At-

tached to each component being moved is some form of encoder to measure the distance traveled. The computer has to monitor the movement being measured by the encoder, determine how far each motor has to run, and control the motor speed in order to effect braking without "overshoot."

(2) Open loop systems using stepping motors. A stepping motor has a large number of poles which when activated in sequence cause the motor shaft to rotate in discrete steps. This approach eliminates the feedback logic which can be up to 70 percent of the drive electronics. The decision to use stepper motors in the drive system was made on the following criteria:

- simple, low cost drive electronics;
- availability of low friction, zero backlash ball bearing screws; and
- ease of control by a microprocessor.

The accuracy of an open loop system depends largely on the mechanism connecting the motor to the driven components. Zero backlash ball bearing screws can provide an efficient system for converting rotary motion to linear motion.

Considerable care was taken to design a "balanced" drive system, that is, all the components are matched in capability to produce an economical but secure drive. The microcomputer capability is matched to the stepping motor speed, and the motor torque and lead screw drive matches the mass of the scanning system.

Stepping motors with 200 steps per revolution are readily available, and if, for instance, they are combined with a ball bearing screw of one millimetre pitch, give an increment size of 5 micrometres. Because a component will be sent to the nearest whole step of the desired position, the actual error in position will be two-and-one-half micrometres plus errors due to imperfections in the drive systems.

The stepping motors are driven at rates of up to 1000 steps per second by the microprocessor, giving a slewing speed of 5 mm per second. This allows the optical heads to traverse the 200-mm viewing area in 40 seconds. In practice, the operator would only move at a fraction of this speed. The stepping motors are controlled by a program running in a single chip microprocessor, which is in turn controlled by a host computer.

There is no need for resolution below 6 micrometres except in a few specialist photogrammetric applications. Marks (1976) specifies a tolerance of 6 micrometres for triangulation, and 8 to 13 micrometres for ground information for topographical mapping.

The SD-4 System

The SD-4 System consists of the optical/mechanical components together with the controlling microcomputer and associated controls. The system must be linked to a host computer to allow the interactive "analytical" software to function. The host computer can be a standard 16-bit minicomputer or may be a mainframe computer. In operation, the SD-4 monitors the hand controls, informs the host computer, and drives the lens system. The host computer uses the hand control data as input to the transformation equations to determine movements in the plotter drive systems. This cycle must occur at least 30 times per second to achieve a suitably responsive system for the operator.

Mechanical Description

Carriage Layout

The SD-4 is approximately 800mm long, 550mm high, 450mm wide and weights approximately 45 kg.

A central scanning carriage runs along two horizontal guide shafts which are mounted one above the other in a steel space frame. The carriage is mounted vertically, and is moved horizontally along the shafts by a precise recirculating ball screw assembly driven by a stepping motor. The bottom guide shaft has been designed to take the full weight of the carriage without deflection, and the carriage is located on this shaft by means of special linear races. The top shaft acts to prevent the carriage from rotating about the bottom shaft, and the carriage is guided along it by means of two ball races, one on each side of the shaft.

At the bottom of the carriage are two stepping motors which each drive a precision recirculating ball screw. There is one motor on each side of the carriage, and each screw moves an optical head up and down guide shafts mounted in the carriage. The guidance system is similar in concept to that of the central scanning carriage, with each optical head being located on one of its guide shafts by means of linear races, and a second shaft being used to prevent rotation about the first.

Optical System

Each optical head has a moving lens controlled by a small stepping motor to apply y-parallax corrections.

The floating mark optical unit is mounted on top of the carriage, a binocular eyepiece is mounted on the front of the space frame, and the microprocessor and other electronic controls are mounted at the rear of the unit.

The photo carriers are mounted within lighting boxes on each side of the unit. Kappa adjustment is provided for the left photo carrier, and a by adjustment for the right carrier.

Light passes horizontally from each lighting box through the area being observed on each photograph. The rays on each side then travel through a y-parallax lens before being reflected by a front silvered mirror vertically to a front surface mirror on top of the carriage. This mirror reflects the rays horizontally into an objective lens in the binocular eyepiece system, and it also introduces the floating mark image through a small hole in its center.

In photogrammetric terms, the main carriage motor provides a common y motion with the moving lens in each optical head correcting for y-parallax. The motors on the bottom of the carriage provide separate x motions for each photo of the stereopair.

USER CONTROLS

Control of the unit is carried out from two "panniers," each connected by a short cable to the main unit. One pannier has a control for X and Y motion and four function switches, the other has control for Z motion only. A footswitch is provided to indicate when data are to be stored, and this is linked in parallel to switches on each of the hand controls. Each pannier also has controls to vary the light intensity of the photo lighting box, and the light intensity of its floating mark, and the sensitivity of the hand controls.

The panniers have been designed as separate units so that the actual hand controls (which may be joysticks, handwheels, or rolling ball controllers, etc.) can be varied according to the operators preference. In addition, some people who are strongly left handed may prefer X-Y controls to be on the left with the Z control on the right.

COMPUTER CONTROL

The SD-4 communicates with its host computer by means of a standard RS232 interface, and its power supply comes from a small separate floor mounted unit which will operate from 240 volts AC, 110 volts AC, or a 12 volts DC supply. See Figure 1 for interfacing options.

The mechanical components have been designed to provide good repeatability, and, if given a position specified in terms of motor steps, the optical heads will always go to the same positions within the steel space frame. Final accuracy is achieved by the application of corrections in software to allow for systematic mechanical errors. This approach allows all repeatable systematic errors in the drive systems to be compensated for in order to achieve a high overall accuracy. An important design goal in the drive systems was to eliminate nonrepeatable errors such as backlash. See Figure 2.

SOFTWARE DESIGN

The SD-4 software has been written in a highly modular fashion in order to facilitate easy maintenance and to allow "application" routines to be added with a minimum impact on the standard software. A layered approach has been adopted in the standard software to enable the user to easily interface to the machine at the appropriate level.

A STRUCTURAL APPROACH

LEVEL 1. This is the highest level of machine control, which is at present written in ANSI FORTRAN IV. At this level the programs deal with a theoretical SD-4 able to move two optical heads in two directions, x-left, y-left, x-right, and y-right. All movements are in millimetres in each of these four directions. This is considered to be a "perfect" machine, that is, it has no mechanical or optical defects.

LEVEL 2. The subroutines at this level are also written in FORTRAN IV and convert the theoretical machine from LEVEL 1 into the real SD-4. It converts the x_L, y_L, x_R, y_R motions into real motions using the five available drive systems, the x-left, x-right, y-common, Delta y-left, and Delta y-right. It also consults a lookup table of the systematic errors in the SD-4 and applies the appropriate corrections to the motors to make the machine appear "perfect" to the LEVEL-1 programs. At the same time lens corrections can be applied from the same lookup table. The millimetres used in LEVEL 1 are converted into motor steps to be sent to the motors. The mechanical correction data are obtained by running a special "calibration" program using a set of grid plates to derive the corrections which are stored in a disk file. The lens distortion parameters are read from a lens data file.

LEVEL 3. These subroutines are written in assembler language. They perform all the communication with the microcomputer controlling the SD-4. They send updated step positions for each

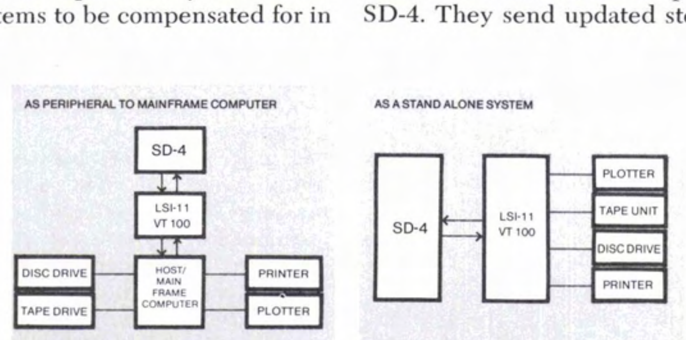

FIG. 1. Interfacing options.

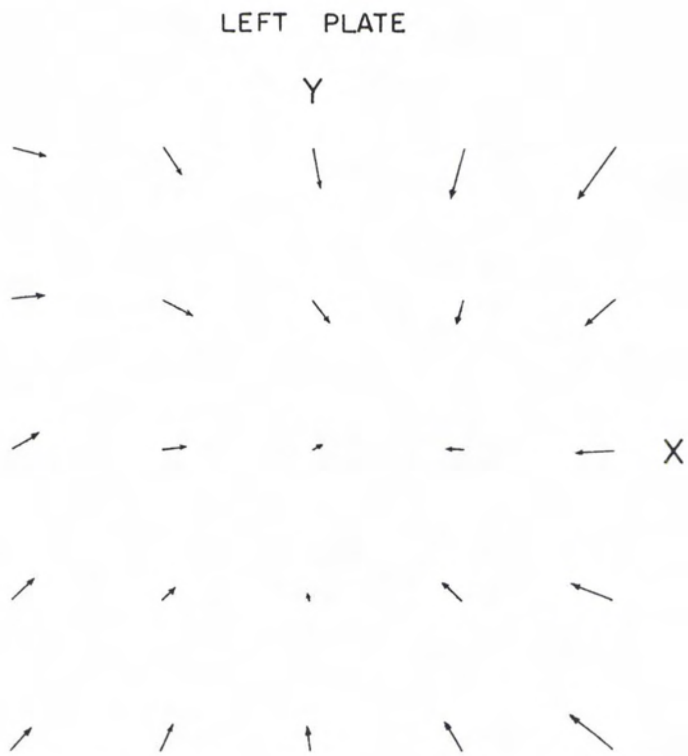

FIG. 2. Typical calibration result (scale: 1 mm = 6 micrometres).

motor to and receive updated hand control status from the SD-4.

LEVEL 4. The microcomputer firmware communicates with the LEVEL 3 routines and performs the actual stepper motor control. It also monitors the hand controls and function switches and updates the host computer when necessary.

STANDARD SOFTWARE FOR THE OPERATOR

There are two main groups of programs supplied with each machine. The first group comprises routines to test and calibrate the system, and it includes the following operations (see Figures 3 and 4):

- Grid plate calibration of the main drive systems;
- Calibration of the y-parallax drives;
- Performance testing of each hand control;
- Testing of all switches including the motor drive limit switches;
- Testing of all function keys on the panniers; and
- Performance testing of each motor and drive system.

This group has been provided so that an operator can thoroughly check and calibrate the system and, if necessary, isolate any potential problem. The plotter hardware is of modular design; therefore, if a problem is detected, the offending component can in most cases be simply unplugged and replaced. As the SD-4 has shown itself to be very reliable, the main use of this group of programs has been to calibrate the equipment, and provide confidence tests for operators who are not familiar with the system.

The second group is a series of programs to run the SD-4. They include interior orientation, fiducial checks, relative orientation, absolute orientation, and various routines for capturing data and plotting.

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Program to test and calibrate the SD-4
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    1. Test switches
    2. Test individual motors
    3. Test the Joysticks
    4. Test all motor functions
    5. Calibrate the plotter
    6. Motor Reliability Test
    7. Exit


  Enter your selection
```

FIG. 3. Sample test menu.

```
          QASCO  SD4 MENU                   19-JAN-82      00:25:03     V0.80
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 1  Set Model Parameters                     Model      Not Done
 2  Interior Orientation                     Interior   Not Done
 3  Measure Fiducial                         Fiducials  Not Done
 4  Relative Orientation                     Relative   Not Done
 5  Absolute Orientation                     Absolute   Not Done
 6  Digitise Data
 7  Output Data to Disk File
 8  Set X-Y Plotter Parameters
 9  Output Data to Printer/Terminal
10  Set Floating Mark Height
11  SD4 Functions
12  Set Soln Convergence Limits
13  Exit


    Input Your Selection
```

FIG. 4. Sample operating menu.

At all stages the operator is prompted by messages on the CRT screen, and results are displayed on the screen as work progresses. Routines are selected from a menu which is displayed on the CRT screen on request from one of the function keys located in one of the panniers. This menu includes information as to the current status of the job, and the programs prevent selection of a routine out of logical sequence. For example, one cannot proceed to the absolute orientation phase before completing a successful relative orientation; however, the operator can go back to and repeat any stage of the orientation simply by requesting the menu and selecting the desired routine.

Reports on the fiducial check, relative orientation, and absolute orientation can be sent to a printer if desired, and the data may also be stored on disk file for use later.

DISK FILES

There are four basic types of disk files used by the software.

The correction file for the SD-4 is created by the test and calibration software and is used by the programs which run the plotter. It contains tables of corrections for the main drive systems and the y-parallax drive systems.

The lens file has details about each lens which may be used by the system. These details include the focal length, calibration of the fiducial marks, and constants for the standard lens distortion formulae.

The job file contains details such as flying height, lens number, and orientation details for each photograph. It also has a list of all control points in the job and their coordinates. The file is created initially by a job maintenance program; then, as each model is oriented, the results of the orientation are written back to the file to facilitate restarting a model if this procedure is necessary.

Output files contain digital information extracted from each model or group of models. The data may be in the form of strings of coordinates preceded by an identifying header block, or it may consist of individual coordinates each with identifying codes. The actual final structure of output files can be determined by the user, and standard routines are available for storing data such as roads, contours, sections, etc.

SUMMARY

The rapid development of the minicomputer has meant that many conventional ideas relating to the physical configuration of stereoplotting hardware are no longer valid. That these ideas can be discarded successfully has been demonstrated by the Qasco SD-4 Stereodigitiser. The effective marrying of the design concepts outlined in this paper with recent computer technology has enabled the application of photogrammetry to be spread into many new and diverse fields. Non-aerial, non-vertical, non-topographical, non-metric cameras, non-experienced operators, are all areas which can be opened up with a simple, low-cost, analytical stereoplotter such as the Qasco SD-4.

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