APS-1 ANALYTICAL PLOTTING SYSTEM

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ABSTRACT

The analytical plotting system APS-1 developed by Xi'an Research Institute of S&M, China, and Hang Guong ("Aero-optics") factory is constitute of stereocomparator, plotter, microcomputer, interface and software. The system works under control of microcomputer. The intelligent I/O interface performs data collection and servo control functions.

The APS-1 is provided with complete photogrammetric software, the more important of which are real-time loop program with frequency of 30 times/second operating in interrupt mode, large-scale (1:5000 and large) mapping program, close-range photogrammetric program for non-metric cameras, program for independent models aerotriangulation with up to 200 models. The photogrammetric operating system has both English and Chinese versions. The operation on APS-1 is easy and straightforward. The system accuracy is ±6μ in image coordinates and ±0.1mm in plotting.

INTRODUCTION

Analytical plotting system is an universal stereoplotting system different from analog plotting system. It realized one to one object-image correspondence by the control of computer. Therefore analytical plotting system has many significant advantages over analog ploter. The main advantages are:

High operational flexibility. There are few limits to focal distance and the picture format of the sensor. It is capable of accomplishing various photogrammetri tasks including digital plotting, capable of effective correction of various errors and so on.

High efficiency. It has high speed of orientation operation and possesses higher plotting efficiency by the aid of computer-assisted plotting program than the conventional plotting instrument.

Due to the above mentioned outstanding advantages, great achievement have been obtained in recent ten years since the introduce of the analytical plotting system.

The APS-1 analytical plotting system was commonly designed and developed by Xian Surveying and Mapping Institute and the Hang Guong factory. It was designed in 1985 and accomplished in 1987. The experiments made show that the image coordinate measurement accuracy is ±6μ.

APS-1 can fulfill various photogrammetric tasks. The basic functions are:

Graphic plotting. It is capable of large scale plotting with the computer-assisted mapping software.

Aerial triangulation. On-line aerotriangulation data acquisition and off-line independent model block adjustment.

Digital plotting. It is capable of formation of digital cartographic file suitable for various tasks.

Close-range photogrammetry, photographs obtained with
non-metric camera can be handled with photogrammetric method.

In this article all parts and the main characteristics of the APS-1 are described as following.

THE STEREOCOMPARATOR AND PLOTTING TABLE

APS-1 uses 2 dimensional coordinate measurement to substitute for the 3 dimensional coordinate measurement, carrying out one to one corresponding relationship with computer high speed operation and real-time control to replace the guide arm. Therefore, the stereocomparator and the plotting table are the digital data acquisition, servo drive and graphic output system of the APS-1. They are the principal constituent of the APS-1.

The accuracy order of a APS-1 is to a great extent accuracy of the structure.

Mechanical construction of the stereocomparator

The coordinate measurement device consists of a housing and a corpus.

The housing has four foot cushions and lifting screws for levelling the horizontality of the instrument. There are three column to support the corpus. Once levelling the instrument, the other two regulating columns will support the corpus for maintaining the stability of the housing. The housing is made of casting with reinforcing bars to prevent from the deformation (Figure 1). The photo-carriages of the stereocomparator are two independent measurement systems. On the bottom surface of the corpus as a reference fixed the y guideway and y support guideway. The y slide along y guideway moves in y direction. On the x slide is installed x guideway and x support guideway photocarrage is moved along x guideway in x direction (Figure 2). The coordinate measuring error due to the non-linearity and the non-verticality of the guideway is the main error source. Therefore, there is demand for higher processing accuracy to the linearity of the guide side of the x and y guideways. The verticality of the x and y guideways is realized with the two eccentric bearings.

The drive motor is fixed on one end of the x and y leading screw through the shockproof shaft coupling. Leading screw is joined to the photo-carriage through the nut. The straightedge raster is used as a measurement mechanism. When measuring the movement value of the image point, the computer transmits it to the leading screw through the digital-to-analog convertor and causes the photo-carriages to move in x and y directions. (Figure 3)

Optical system of the stereocomparator

Optical system is employed for the stereoviewing and plotting. It consists of projection system, alignment system and telescopic eyepetem. (Figure 4)

The illuminating system (1) through the condensing lens provides photocarrage (4) with brightness no less than 2000 Lambert/foot. Objective lens (6) presents the diapositive image of the photocarrage on to the floating mark surface, the focal surface of the objective lens (13) acts as a floating mark surface (9). The light beam passing through the objective lens (13) becomes a parallel beam. The pechan
prism(14) is installed in the parallel light path for rotating image and converting the prism group inner-basis and outer-basis, the parallel beam through the deviating prism(15) entries to objective lens(17) and focuses on the focal plane of the eyepieces(19). There are add reflection so the instelled diapositive should be downward, and the emulsion should be upward. Binocular single observation is can be realized with the basis variable prism group.

In order to provide operation stability of the measurement and good stereoscopic effect of the instrument, certain limit should be made for the parallel beam aberration of the emergent this is the divergent aberration should be less 60', the convergence less 15' and the coplanarity less 15'.
Plotting table

The maximum effective area of the digital plotting table is 800×1000mm, having reflect and transparent light illumination for scribing and plotting. Plotting head is guided along x guide-rail, the x guide-rail moves along the y guide-rail. Therefore, the demand for the linearization of the y guide-rail much more rigid than for x guide-rail. The plotting head has three pen holders. The counting and positioning raster resolution of the plotting table is 20um, the root-mean-square error of coordinate < ± 0.1mm.

Technical parameter

The measurement range of the photocarriage 230mm×230mm. Image coordinate measurement accuracy < ± 16um. Resolution of the linear encoder 5um. Diameter of the floating mark 40, 20um. Magnification of the optical system 8x, 16x; Resolution of the optical system 6 line pairs/mm; (i.e. no less than 50 line pairs/mm for 8x, and no less than 90 line pairs/mm for 16x); Field of view 30mm for 8x, 15mm for 16x; Effective area of the digital plotting table 800×1000mm; Rotating range of Pechan prism ± 50°; Coordinate RMS error 0.1mm.

THE COMPUTER AND ITS INTERFACE

APS-1 Analytical Plotting System is essentially a computer real-time control system. The stereo-comparator and the plotting table are the peripherals of the computer. The interface is the link installations interconnecting the computer, stereo-comparator and plotting table. The task of the interface is to accomplish the information interchange, namely, through the interface the computer carries out real-time checking and acquisition of the abovementioned condition informations, for example the present position of
the floating mark. Stereocomparator and plotting table fulfils the corresponding operations according to the computer's command, for example the floating mark or penhead is pointed to a certain deretion.

The Computer
The APS-1 is equipped with a M-24 Microcomputer. It is compatible with IBM-PC/XT, capable to operate software supported by PC-DOS and MC-DOS. The hardware consists of:
CPU basic frequency -- 8 M,
Internal memory -- 640 KB RAM,
360 KB double-surface, double-density, floppy disc drive,
10 MB hard disc drive,
440×200 green display and keyboard.
The software includes:
English operating system PC-DOS,
Chinese operating system CC-DOS,
and Fortran-77, compile BASIC, MACRO assemble MASM.

Interface
APS-1 adopts I/O addressing, the processor servo close loop control interface. Figure 5 is the block of its physical instellement interface.

With this scheme, the computer addresses to every physical component of the Stereocomparator and plotting table such as x,y according to the I/O. When carrying out read and write interrogation to these addressing equipment the information exchange is realized. Once the equipment will accomplish close-loop servo control, the interface operates in interrupt mode and every 30 ms transmit one interrupt request. The computer interrupts the executive routine according to the interrupt request, enters interrupt service and carries out real-time loop routine.

Servo drive system
The servo drive system of APS-1 is operated under the control of Z-80A processor, the actuator can be either step motor or moment servo motor.

Figure 6 is the block diagram of the servo drive of the stepper motor. In this instance, in addition to accomplishing
the ring dispatcher function, the Z-80 A processor, by means of its fixed variable-speed software, carries out real-time modulating of the operating frequency of the stepper motor in order to increase the operating speed and to improve the stability. In addition, the Z-80A also fulfills some control and calculation tasks, e.g. overrun control and interpolation operation of the penhead.

Figure 7 is the block diagram of the application of the torque direct current motor as an actuator.

![Figure 6: Servo Option (1)](image)

![Figure 7: Servo Option (2)](image)

Both of the servo drives operate in a manner of increment, e.g. the computer transmits the object positions of the carriage with its relative coordinates, the servo system continuously measures the deviation between present position and object position, through it forms control signal of the motor until the moves to the place.

Control Panel

The control panel is located on the front side of the stereocomparator. The console controls include four buttons and two switches in the center portion. Two buttons in the midst of the four are used for regulating the brightness of the right and left floating marks until formation of bright and dark floating marks. The other two buttons outside are used resolutely to regulate the brightness of the horizontal parallax. The switches are used for binocular left viewing and right viewing, and Ortho-Pseudo base distortions. There are 24 knobs and 8 switches located the right and left sides of control panel. These knobs and switches have different functions, for example, clear zero knob for setting the base point of the carriage coordinate system; drawing table knob for setting the plotting table in on-line mode; Model knob, when pressed inward, it is in model operation mode, conversely, in photograph operation mode; Photograph knob indicates only driving one carriage, if simultaneously depressing the right foot switch, it indicates only driving right carriage, conversely, only drives left carriage.

In addition, there are left foot and right foot switch. The left foot switch is primarily used to determine some measurement has been finished. When program makes inquiry, it is used to generate positive reply. If a negative reply is provided, depress the right foot switch.
Some of these knobs can be defined by user, the details of operation instruction are described in the "APS-1 Analytical Plotting system software manual".

APS-1 SOFTWARE SYSTEM

APS-1 software system consists of operation program, real-time loop program, application software package and user software developing system.

APS-1 has more functions, capable of accomplishing mapping, control extension and digital mapping.

APS-1 has also close-range photogrammetric program suitable for non-metric camera, and special software suitable for reconnaissance of the electric transmission line and road route. The software system includes also user software developing system in order to meet the requirements of the customers for developing new software functions.

Real-time loop program development

The real-time loop program is the heart of the software system, by means of this program operator control the whole system in order to maintain the one-to-one corresponding relationship between object and image.

The loop program operates in interrupt manner, execution cycle is about 30 ms, it is function are:

- Data acquisition: model coordinates sent from handwheel and footwheel; carriage coordinates of the right and left carriage; coordinates of the plotting table;
- Computation: model-to-ground conversion (including Earth-curve correction); model-to-photograph conversion (including lens distortion correction); photograph-to-carriage system conversion (including negative distortion correction);
- Drive control: control floating mark and/or penhead movement.

The source code of the loop program is programmed in macroassembly language, it performs data communication with application program through the common parameter area installed by the system.

Application software package

Application software package consists of programs performing various photogrammetric tasks and their corresponding service programs. These programs are divided into following:

- Orientation programs: inner orientation (IO); Relative orientation (RO); Absolute orientation (AO); Table orientation (TO);
- Mapping programs: on-line mapping program (MAP), the program is capable to draw various symbols, elevations broken lines, curves, populated place, plotting of points program (TPP), it is capable to drawing the mapframe, kilometer network, control points and so on;
- Aerial triangulation programs: network forming program (AT), used for data acquisition of the pass points; single strip adjustment program (ATC); Block adjustment software package (MOAM), it consists of 4 programs, adopting the independent model block adjustment is enable to compute a block with ten strips, each strip having 20 models;
- Digital mapping program; digital terrain model sample
program (DTM) is used in collecting elevation data along the terrain profile or ground grid. The results enter the disc fides.

Close-Range photogrametric program; (DLT) program applies direct linear transformation algorithm to process photographs obtained with the non-metric camera;

Service Prigcam; Parameter enter program (EP); point operation program(PO); Real-time coordinat display program(DD);

Photocarriage calibration program (CLIBP) and Drawing table calibration program (CLIBT);

Application software package includes length, area, volume and slope computation program.

APS-l software system has two editions respectively in Chinese and English hints, simpler and easier to use. The description in details are in "APS-l user's manual".

User software development system

When user need to extend the instrument operation functions, the following two points should be payed attention to:

Gain a clear idea of the main parameters definition and application method in the common parameter area, the size of the APS-l common parameter area is 1KB, in which each variable is strictly defined. Common parameter area is stored in the hard disc as a disc file, generally, application program always first read out the disc file, and write the common parameter area in the disc file before the program terminates the operation.

User program realizes real-time control of the APS-l through the exchanging with the common parameter area of the loop program.

APS-l has common-use subroutine library, it is very useful and necessary for the users.

The above mentioned circumstances can be referred to "APS-l Analytical Plotting System software reference manual".