# APS-1 ANALYTICAL PLOTTING SYSTEM

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## ABSTRACT

The analytical plotting system APS-1 developed by Xi'an Rasearch Institute of S&M,China,and Hang Guong("Aero-optics') factory is costitute of stereocomparator,plotter,microcomputer, interface and software.The system works under controe of microcomputer.The intellugent I/O interface performs data collection and dervo 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 operatimg in interrupt mode; large-scael(1:5000 and large) mapping program;close-range photogrammetric program for non-metric cameras;program for independent models aerotriangutation with upto 200 models. The photogrametric operating system has both English and Chinese versions. The operation on APS-1 is easy and straigtfoward.The system accuracy is $\pm 6u$ in image coordinates and $\pm 0.1mm$ in plotting.

## INTRODUCTION

Analytical plottung 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:

Hiqh 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 effecfive correction of various errors and as on.

Hiqht efficiency .It has hiqh speed of orientation operation and possesses hiqher 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 resent 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 Hing Guong factory. It was desiged in 1985 and accoplished in 1987. The experiments made show that the image coordinate measurement accuracy is $\pm 6u$

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

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

Aerial tringulation.On-line aerotriangulation data acquition and off-line independent model block adjustment.

Dingtal 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 discribed as following.


## THE STEREOCOMPARATOR AND PLOTTING TABLE

APS-1 uses 2 dimentional coordinate measurement to Substitute for the 3 dimentional 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 acquistion, servo drive and graphic output syefem 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 horizohtality of the instrument. There are three column to support the corpus. Once levelling the instrument, the orther two regulating columns will support the corpus for maintaining the stability of the housing. The housing is made of casting with reinforing bars to prevent from the deformation (Figure 1). The photo-carriages of the stereocomparator are two independent measurement syetems. 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 souro. 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 transmites it to the leading screw through the digital-to-analog convertor and causes the photocarriages to move in x and y directions. (Figure 3)


Optical syetem of the stereocomparator

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

The Illuminating syetem (1) through the condensing lens provides photocarriage(4) with brightness no less than 2000 Lambert/foot. Objective lens(6) presents the diapositive image of the photocarriage 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
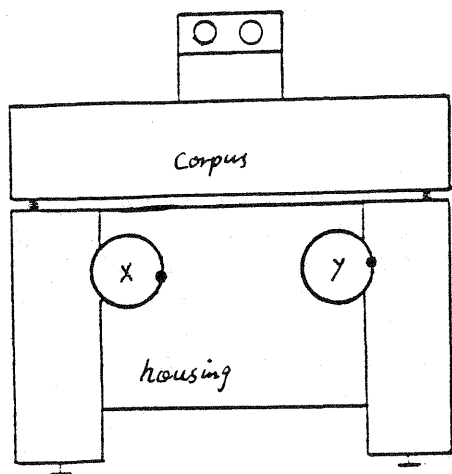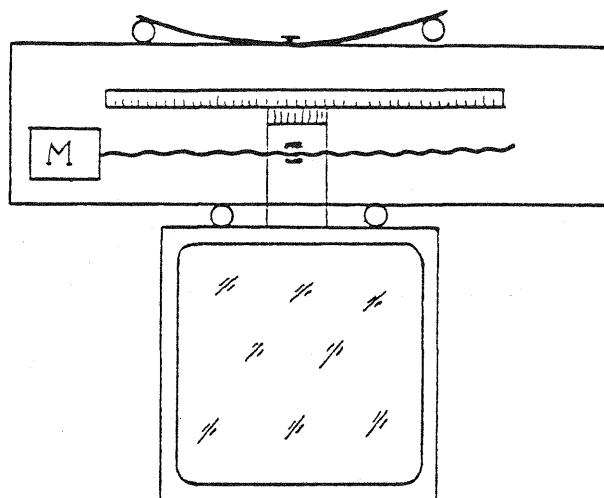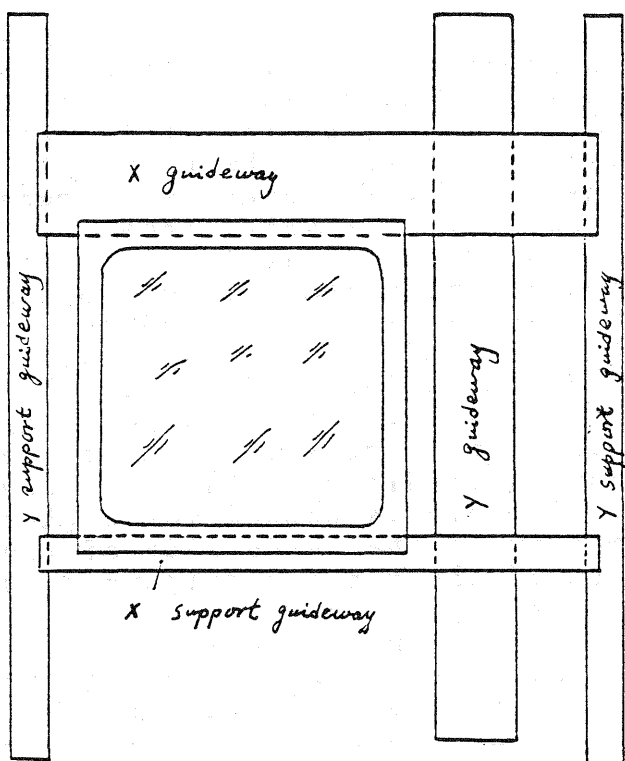
Fig. 1



Fig. 3



Fig. 2

prism(14) is instelled in the parallel light path for
rotating image and conveting 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'
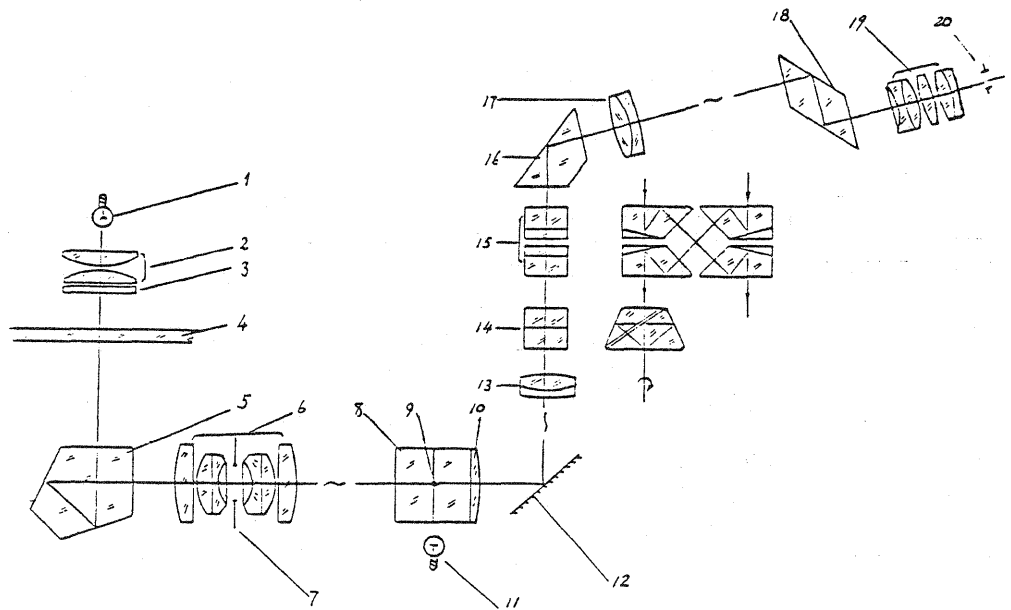the convergence less 15' and the coplanarity less 15'.

Fig. 4

## Plotting table

The maximum effective area of the digital piotting talbe is 800✕1000mm, having reflect and transparant light illumination for scribing and pliotting. 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$\leqslant\pm$0.1mm.

## Technical parameter

The measurement range of the photocarriage 230mm✕230mm. image cooroinate measurement accuracy$\leqslant\pm$6um. Resolution of the linear encoder 5um. Diameter of the floating mark 40, 20um. Maguification of the optical system 8✕, 16✕; Resolution of the optical system 6 line pairs/mm; (i.e. no less than 50 line pairs/mm for 8✕, and no less than 90 line pairs/mm for 16✕); Field of view 30mm for 8✕, 15mm for 16✕; Effective area of the digital plotting table 800✕1000mm; rotating range of Pechan prism $\pm$50° ; coordinate RMS error of plotting $\leqslant\pm$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 instellations interconnecting the computer, stereocomparator 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 acguision of the abovementioned condition informations, for example the present position of

the floating mark. Sterrocomparator and plotting table fulfils the corresponding operations according to the computer's command,for exsample the floating mark or penhead is pointed to a certain deretion.

## The Computer

The APS-1 is eguipped 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 freguency --8 M ,
Internal memory -- 640 KB RAM ,
360 KB double-surface, double-density,floppy disc drive,
10 MB hard disc dirve
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.
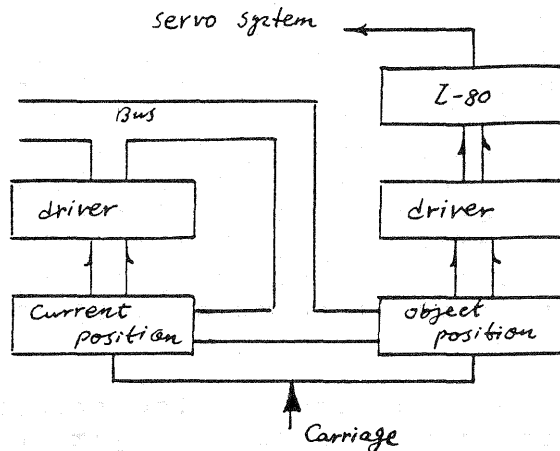


Fig.5 interface block diagram.

With this seheme,the computer addresses to every physical component of the Stereocomparator and plotting table such as x,y according to the I/0.When carring out read and write interrogation to these addressing equipment the information exchange is realiged. Once the equipment will aecomplish 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 servce and carries out real-lime 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 accomolishing

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 fiequency of the stepper motor
in order to increase the operating speed and to improve
the stabilitation. In addition, the Z-80A also fulfuls some
control and calcnlation task,e.g.overrun control and
interpolation operatoon of the penheacl.
    Figure 7 is the block diagram of the application of the
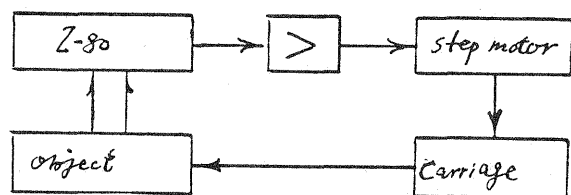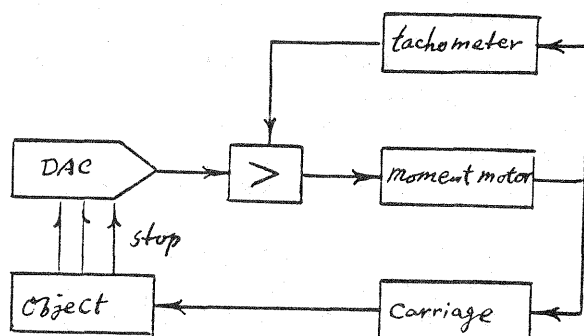torque direct current motor as an acturtor.

Fig.6    servo option (1)

Fig.7    servo option (2)

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

Contorl Panel
    The control panel is located on the front side of the
stereocomparator. The console controls include four bottons
and two switchs in the center portion. Two bottons 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 bottons outside
are used resoectively to regulate the brightness of the
horizontal parallax. The switchs are used for binocular left
viewing and right viewing,and Orttho-Pseudo base pbserratiuns.
There are 24 knobs and 8 switchs located the right and left
sides of control panel. These konbs and switohs 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 photogroph operation mode; Photograph
knob indicates only driving one carriage,if simultaneously
depressing the rightfoot switch, it indicates only driving
right carriage, conversely,only drives left carriage.
    In addition,there are leftfoot and rightfoot switch. The
leftfoot 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 rightfoot switch.

Some of these knobs can be difined by user, the details of operation instruction are descrited 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 developping system in order to meet the requirements of the customers for developping 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 copresronding relationship between object and image.

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

Data acquistion: model coordinates sent from hanclwheel and footwheel; carriage coordinates of the right and left carrige; coordinates of the plotting table;

Computation: model-to-ground conversion (including earth-curvature 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 derided into following:

Orientation programs: inner orientation(IO); Relative orientation(RO);Absolute orientatian(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 acquistion of the pass points; single strip adjustment progrorm (ATC);Block adjustment software package (MOAM) ,it consists of 4 programs,adopting the independent model block adjustment is enabhe 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 entere the disc fides;

Close—Range photogrametric program: (DLT) program applies direct linear transfotmation 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);

Phatocarriage calibration program(CLIBP) and Drawing tablc calibration program (CLIBT);

Applicction software package includs length,area,volume and slope computation program.

APS—$_1$ software system has two editions respertively in Chinese and English hints, simpler and easeir to use. The description in defails are in "APS—$_1$ user's manual" .

User software develapment 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 difination and applicatuion method in the common parameter area,the size of the APS—$_1$ common parameter area is $_1$KB, in which each variable is strictly difined.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 teminates the operation.

User program realizes real—time control of the APS—$_1$ through the exchanging with the common parameter area of the loop program.

APS—$_1$ has common—use subroutine library, it is very useful and necessary for the users.

The above mentioned circumstances can be refered to "APS—$_1$ Analytical Plotting Sysem softwane reference manual" .