AIPS MEMO NO. 11

A Computer-Assisted Astrometry System
(Charlottesville Version)

DRAFT 14:34:59 3 June 1982 DRAFT

The two-axis measuring engine in room 223 ("Optical Data Lab") of the Edgemont Road building is now available as a computer-assisted astrometry system. The system measures positions of objects on the POSS prints, using the SAO catalog as a source of reference stars. Final settings made on POSS prints with the system appear to have errors (one sigma) of about half an arcsecond. A copy of the current version of the software has been made and this copy will be frozen (assuming no gross bugs are found) while development work continues (see "Work in Progress" below). The purpose of this memo is to describe how to execute this frozen version of the software. Almost identical facilities (plates, engine, and software) are available at the VLA. For further information, or to report inadequacies in the software or in this documentation see Don Wells (Rm. 210, Edgemont Rd., ext. 277).

The Measurement Process

1. Enable the Hardware. See "Devices Which Must be Powered".

2. Enable the Basic Software. See "Terminal Keyboard Conventions", and "VAX Login Procedure".

3. Start FINDER. See "Starting Program FINDER".

4. Initialize the coordinate system (done only for first execution of FINDER). See "Coordinate Initialization" and "Final Settings".

5. Enter the Object (field) Name. See "Acceptable Object Names".

6. Enter Approximate Coordinates for the Object (field). See "Survey Plates and Catalog Stars", and "Mounting the POSS Print".

7. Measure the Reference Stars. See "Reference Star Measurements", "Finding the First Reference Star", and "Final Settings".

8. Measure the Program Object(s). See "Program Object Measurements" and "Final Settings".

9. Run OPTFIT to Reduce the Measurements. See "Notes on OPTFIT".

10. Quit, or repeat steps 3-9 for another object. See "Shutdown Procedures".

The Measuring Engine

The principal piece of hardware in the system is the Mann two-axis measuring engine, which has a 14-inch stage. The engine is of classical design, depending on precision screws for its accuracy. It was built some years ago and NRAO obtained it from government surplus. An optical encoder and stepping motor have been installed on each axis. Each motor is connected to its screw through a clutch which disengages when the motor is not driving. This allows the user to make final settings with the original handwheels. A small control panel has been added to the front of the engine.

The control panel, stepping motors, and digital encoders are interfaced to a microcomputer. The microcomputer is interfaced to the VAX computer. Software in the VAX can communicate with the microcomputer to command motions of the measuring engine and read its current location.

NOTE

> Any slew motion being performed by the microcomputer can be halted by pressing the ABORT button on the front panel of the measuring engine. The VAX software is informed about the ABORT by the micro and usually will accept this as terminating the motion it had commanded. The present VAX software sometimes will immediately command a restart of the slew. In such a case just ABORT again. The VAX will eventually accept the ABORT.

The original eyepiece of the measuring engine has been replaced with a General Electric CID solid-state TV camera (244 rows of 248 pixels each). Users view the POSS prints with a TV monitor, thereby avoiding eyestrain in long measuring sessions. The CID camera has a stable, drift-free geometry. A flourescent lamp in the shape of a ring is provided to illuminate the prints.

Devices Which Must be Powered

- Mann engine (switch on front panel). Note that often a dust cover is over the engine (see "Shutdown Procedures"), and this cover should be removed whenever the electronics are powered to avoid overheating.

NOTE

> Press the small red reset button on the front panel of the electronics rack which is under the left side of the Mann engine table once just after turning on the power. An automatic power-on reset is expected to be installed soon and will eliminate the need for this operation.

- Visual 400 terminal (switch on right-hand side of monitor unit)
- Aristo Flourescent Ring Light (switch on small black power supply box on top of the measuring engine). The TOP LIGHT switch on front panel must also be on.

NOTE

> The Sanyo monitor might be dark because its BRIGHT control (behind small access door at bottom of front of monitor) has been turned down. Currently the Sanyo CONTRAST control should be at maximum (full clockwise), and BRIGHT should be adjusted for best contrast.
>
> The Visual 400 screen goes dark after several minutes with no activity. Press the SHIFT key momentarily to restore it.

Television System

The TV field of view of the Charlottesville engine is only 2.4 by 2.0 millimeters (161 by 134 arcseconds, 2.7 by 2.2 arcminutes). The field of the TV is flipped in the E-W direction: North is at the top of the screen, and East is on the RIGHT, not the left. Note that there are two focus controls (knurled rings). One is the 'Reticle Focus', the other is the 'Plate Focus'. They should be adjusted separately. The reticle crosshairs may be rotated slightly. Beware of this when making final settings.

Terminal Keyboard Conventions

All input text is terminated by pressing the RETURN key on the Visual 400 terminal keyboard. The DEL key (hold down SHIFT and press DEL) may be used to delete mistyped characters prior to issuing RETURN. Programs FINDER and OPTFIT expect upper case input for their command codes. It is convenient to lock the keyboard in upper case. A red light on the CAPS LOCK key indicates that the Visual 400 terminal is locked into upper case (press CAPS LOCK to turn it on).

VAX Login Procedure

First press RETURN on the terminal. The VMS operating system should respond with

```
Username:
```

which indicates that it wants the user to log in. Now enter

```
MANN
```

followed by the RETURN key (see "Terminal Keyboard Conventions"). VMS should respond with

```
Password:
```

Enter

```
MANN
```

again as the password (characters will not echo), and again terminate the message with RETURN. This process logs in to directory [MANN]. VMS will print various messages, the login procedure of [MANN] will start up the communication program ZZMANN, and finally VMS will give its usual dollar sign prompt.

Starting Program FINDER

Enter command

```
RUN FINDER
```

This should awaken program FINDER which is the current astrometry program. FINDER will want to initialize the coordinate system if this is its first execution in the current login. It will then present the user with a series of questions and options.

Coordinate Initialization

The program will ask for the current X and Y coordinates. The X handwheel is on the right, and the Y handwheel is on the left as you face the front of the engine. Rotate each handwheel clockwise up to the next integer millimeter, and enter the two integers into the terminal separated by a space (X first, then Y). This setting needs to be accurate to only 0.1 millimeter. Beware of parallax in reading the dials. The recommended procedure is to rotate clockwise up to 0 microns and read the nearest integer millimeter. If the engine is positioned at or near either of the limits of either of the axes move it away from the limit because the microcomputer will refuse to accept a position which it considers illegal, and the software will simply ask for the initial coordinates to be entered again.

Final Settings

Final settings should ALWAYS be made with the handwheel rotating clockwise to avoid errors due to backlash. The Charlotttesville engine has backlash in the screw-and-nut of about 0.1 millimeter. The backlash in the dial readouts associated with the handwheels may exceed a millimeter, but this is not important for reference star and program object measurements because the dial readouts are used only for initialization.

The question of how to define and measure the position of an object on a plate involves some subleties. The eye and brain form an impression of the centroid of an image which has a range of grey levels by some sort of mysterious 'gestalt' process. This process probably works best when the image is small enough to be confined to the fovea centralis, the high resolution region of the retina. Probably it is most effective when the image does not saturate. In this system the limited dynamic range of the POSS-plus-TV-plus-eye combination means that it is a good approximation to say that settings are actually made on the center of a limiting isophot of an image rather than on the intensity-weighted totality of the image. Typically, objects to be measured are faint (m>15). Such faint objects have diameters comparable to the half-width of the seeing profile. Settings on them are made by estimating the centroid of an isophot at a radius of about one arcsecond. The catalog stars are bright (m>10). Their central regions are saturated and so the centroid of an isophot at a radius of one arcsecond cannot be measured for them. This means that it is impossible to derive centroids from the same portion of the point source response for both reference stars and program objects. Examination of survey plates suggests that the centroid location of a contour of the point source response at a radius of, say, 20 arcseconds may differ from the centroid location of a contour at a radius of one arcsecond by more than an arcsecond (i.e., the wings of the point source response are assymmetric). The implication of this is that image centers should be defined and measured with some care in order to avoid producing a magnitude-dependent systematic error in the coordinate system. In the absence of a better procedure, the usual assumption is that the four diffraction spikes around a reference star are formed by the core of the point source response, and that if the crosshairs are positioned on the spikes their intersection is at the centroid location which would be chosen if the object were 100 times fainter. It would be a good thing if someone would check this assumption sometime.

Acceptable Object Names

FINDER puts its measurements into a file whose name is constructed from the object name by prefixing the character M. So if the object name is given as 3C273 the file will be named M3C273. Because file names cannot contain characters like the period or plus sign object names should not contain these characters either. So source names like 1234+567 or 0917-264 should be entered as 1234N567 and 0917S264, and they result in file names M1234N567 and M0917S264.

Survey Plates and Catalog Stars

After the user enters the approximate coordinates of the object or field FINDER will respond with the POSS plate(s) on which the object appears. If there is more than one plate FINDER will want the user to specify which plate he intends to measure. The list of plates has a sequence number (1,2,3,...) in its first column and this is what FINDER wants, not the POSS plate number.

NOTE

> The present plate catalog contains provisional entries for the ESO/SRC plates but they should not be selected. Only the POSS plates are supported by the present system. Anyone who really needs to measure an ESO or SRC plate or to use the AGK3 or Perth-70 star catalogs before the next system release should consult with Don Wells.

Next FINDER will search the SAO catalog to get all SAO stars within a radius of one degree from the approximate position. The user will be asked how many should be used. For example, there might be 22 stars available, but it might be sufficient to measure only the nearest eight stars. After this question is answered FINDER begins the process of measuring the reference stars one by one (see "Reference Star Measurements" and "Finding the First Reference Star"). This process begins by slewing to the first star. As the traverse is likely to be at least 100 millimeters, and the speed is about one millimeter per second, this is a good time to locate and mount the POSS print (see "Mounting the POSS Print").

FINDER sorts the list of potential reference stars in order of increasing distance from the approximate position which was given. If the user specifies that fewer stars should be used (e.g., 8 rather than 22), then the first part of the list (nearest 8 stars) will be retained. Before the measurement process begins another sort is done. The retained list is rearranged so as to approximately minimize the total slewing distance needed during the reference star measurement process. FINDER starts with the first (nearest) star. Next it does the star which requires the smallest slew (maximum of delta-x and delta-y) from the first star, and then the star which is nearest to the second star, and so forth.

Mounting the POSS Print

The print should be positioned on the stage with the lower (South) edge on the marks on the two white stickers which are on the stage, and with the left (East) aligned with the arrow on the sticker on the left. The edges of the print can be held down with the six nice brass weights. The area of the print around the object to be measured can be held down with the 5-inch-square cover glass.

Reference Star Measurements

FINDER begins by slewing to the computed location of the next reference star to be measured. The location is computed from the RA and Dec of the object, the RA and Dec of the plate center, the exposure date of the plate, and an empirical zero point correction. The zero point correction is related to the position of the marks on the stickers on the stage (see "Mounting the POSS Print" and "Finding the First Reference Star"), and it is updated as reference star measurements are made. After the slew FINDER asks for a command code to indicate what it should do. Normally the user adjusts the handwheels to put the object on the crosshairs (see "Final Settings"), and then enters the code M (for measure). FINDER then proceeds to the next object on the list and this step repeats until the list is exhausted. After the third reference star measurement FINDER begins to do a linear regression to predict the location of the next star. After about six stars have been measured this regression is quite accurate. The residuals printout is in units of millimeters (0.01 mm is about 0.6 arcseconds). Note that instead of M the command code S (skip) can be used. If the user wants to proceed immediately to measure the program object the code Q (quit) can be used. After the last reference star is measured FINDER proceeds into the program object measurement phase (see "Program Object Measurements").

Finding the First Reference Star

FINDER slews to the location of the first reference star by absolute coordinates, without the use of an overlay plot. The ability to do this depends on having a catalog of the positions on the sky of the centers of the survey plates, and on mounting the prints in a consistent location on the stage of the measuring engine. The plate centers tabulated in the catalog have an error distribution. The mounting process also has an error distribution. The result is that the initial slew to the first reference star on a POSS print appears to have an error distribution about 8 millimeters wide (one-sigma about 2.5 millimeters). A few cases of errors as large as 6 millimeters have been seen. The TV field of view of the Charlottesville engine is only 2.4 by 2.0 millimeters and this means that usually the first reference star will not be in the TV field at the completion of the initial slew. It is normal to have to hunt a bit to find the star. An important fact which simplifies the process is that reference stars generally show diffraction spikes on the survey prints. In many cases it is convenient to search by hand, but the H (hunt) command is available to facilitate searching over a large area. This performs a spiral search starting at the computed location. The spiral search routine is halted by pressing the ABORT button on the front panel of the engine. This is the normal action when a candidate star is seen to go by on the TV screen. The B (back) command causes the engine to return to the computed position of the object. This option is useful when either a hand search or a spiral search has not turned up a candidate and the user wants to start over. Sometimes there are several bright stars near the computed location and it is not obvious which is correct. In this case choose one and measure it. Sometimes the wrong star is measured without the user being aware of an ambiguity. In either case FINDER will proceed to the second star. Note that FINDER will use the measured position error for the first star as a correction to the computed location for the second star. If no star is seen at the computed location for the second star assume that the initial choice was wrong, and use the R (restart) command. FINDER will return to the original computed location for the first star and another selection can be made. Sometimes one must make a choice for the second star and see whether the third star matches in order to decide whether a correct identification has been made.

Program Object Measurements

FINDER first announces that it is slewing to the coordinates which were originally given as the approximate position of the object(field). When it arrives it offers the same command options as it did during the reference star measurements, but commands S and R should not be used. Issue command M once the final setting has been made. Next FINDER will ask whether another program object should be measured. Answer Y or N. If N FINDER will quit and OPTFIT can be executed to reduce the measurements. If Y FINDER will ask for a name for the next program object. It will then ask for right ascension and declination for the object, and will slew to the specified position. This is useful for measuring a number of optical objects which are associated with radio sources in an area. But if objects of unknown position are to be measured the question is inconvenient. With the present version of the software the proper technique is to enter a slash (/). FINDER will begin a slew to the last position entered (e.g., the original field coordinates), and the ABORT button can be used to stop the slew. Then the engine can be positioned on the desired object and M issued to make the measurement. Apparently there is no limit on the number of program objects which can be measured.

FINDER slews to program objects with the same algorithm which is used to to slew to the reference stars. After 5 or 6 reference stars have been measured the plate constants are known quite well, and x-y coordinates can be computed with an accuracy of better than an arc-second. Therefore the program object measurement phase of FINDER can be used to position precisely on specified locations in order to ascertain whether there are any optical objects at those places.

Notes on OPTFIT

The present version of the software uses a separate program to reduce the astrometric measurements. This program, called OPTFIT, was adapted from the IBM program of the same name by summer student Ken Mighell during the summer of 1981. The program can be executed by entering the command

```
RUN OPTFIT
```

OPTFIT will ask about the source of its input. Enter B (data file) as the answer. OPTFIT will ask for the name of the data file. Enter the name which FINDER assigned (the one beginning with M which appears in the FINDER output which will still be on the screen). If OPTFIT finds the file it will read the information recorded by FINDER and will reduce the measurements. OPTFIT produces a pretty printed file which will appear on the Versatec printer.

Shutdown Procedures

- Log off the VAX. Issue the command

  ```
  LO
  ```

  The VMS operating system should respond with a message. If it is necessary to shutdown while executing FINDER or OPTFIT it will generally be sufficient to enter CTRL-Z (hold down the CTRL key and press Z) when the program is requesting input. This should cause the program to quit and control returns to VMS, as indicated by the dollar sign prompt. Then the LO command can be issued.

- Return POSS Prints to Cabinets

- Power Down the Equipment. Turn off the main power switch on the measuring engine control panel. Turn off the terminal.

- Put the Dust Cover Over the Measuring Engine. It is important to keep dust off the critical parts of the engine (screws and ways) as much as possible. Lint tends to collect on the screws, especially the y-axis screw, and becomes caught between the screw and the nut. As this process proceeds the friction increases, and eventually the stepping motors stall and the screw must be cleaned (a messy process).

Work in Progress

A number of improvements are anticipated, but the current intention is to preserve this frozen system for some time, perhaps as long as six months, and then replace it with another frozen system which will incorporate many changes at once. The intended changes fall into several areas: plates and catalogs, measurement and reduction techniques, hardware, and relation to AIPS.

The present system supports only the POSS plates, and uses only the SAO catalog. The next system will support all survey plates available at NRAO (POSS, Whiteoak, SRC(J), ESO(R), and Infrared Milky Way Atlas). It will utilize all available star catalogs (SAO, AGK3, and Perth-70). It will be able to support new surveys and catalogs as they become available.

The present system uses program OPTFIT to reduce measurements. The next system will do reductions in real time, as measurements are being accumulated. This will facilitate correction of errors, minimization of reference star measurement effort, and quick examination of specified locations on the sky. The operation procedures are expected to be even more interactive and flexible.

The flourescent lamp used in the present system is not bright enough. Also, its output cannot be varied to match the gain of the TV camera. These problems cause the contrast and dynamic range of the TV image to be poorer than they should be. Efforts are being made to obtain a better lamp. The TV image shows certain electronic artifacts which should be corrected.

One of the principal future applications of this system will be to enable us to calibrate the coordinates of digital images produced by optical detectors so that they can be registered with radio images in AIPS. Also, it is desirable to be able to examine optical digital imagery for the presence of optical candidates at the coordinates of radio sources. Generally these operations will require measuring the positions of secondary reference stars in the field of an optical image so that the coordinate system defined by the star catalog can be transferred into the optical image with a two-step astrometric reduction. It is expected that future versions of the astrometry system will be associated with AIPS in a more intimate fashion in order to facilitate this sort of association of star coordinates with digital imagery. The hardware of the IIS TV display used by AIPS is capable of digitizing the video signal of the CID TV camera. Future versions of the system will probably use this capability so that images of small areas of the survey plates can be captured by AIPS as digital images. When the astrometric software has been properly integrated with AIPS such digital snapshots will be tagged with precise coordinate information.