HYDRAASSIGN: A Program for Assigning Fibers with CTIO Hydra

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1. Introduction

This document describes the program **hydraasign**, which takes an input file containing the celestial coordinates of objects and determines a "pretty good" assignment of fibers for the CTIO multi-object fiber positioner "Hydra". This code was originally written for the Kitt Peak incarnations of Hydra (first at the Mayll 4-m, and later for WIYN), and as based on extensive discussions with Taft Armandroff and Sam Barden, with a contribution by Tod Lauer. In 1998, Richard Wolf (NOAO) translatted the FORTRAN code to C++, a process which uncovered several bugs, and transported to CTIO, where Rolondo Cantarutti made many improvements.

The input list should have objects listed in priority order, with the most important objects at the top of the list. The coordinates of clean sky positions and field-orientation-probe stars ("fop stars") should also be included in the same file. (Including a goodly number of fop stars and clean sky positions will provide greater flexibility for placement of fibers on program objects.) The file must also contain the coordinates of the field center, along with a number of things (wavelength, LST, exposure length) that are needed to properly account for the effects of differential refraction.

The output file will contain *all* of the input objects, assigned or not, with fiber assignments indicated with a numerical value in the "STATUS=" field. The stars with assigned fibers are rotated to the bottom of the list, but the input order is otherwise preserved; thus, one can sucessively use each output file as a new input file, with previously assigned stars dropped in priority.

The design goal was to come up with a scheme that would produce "pretty good assignment".

The next section will describe how the assignments are done. Section 3 will describe the input and output formats and how to use the program. Section 4 will summarize the geometrical steps involved. In the Appendix we give some suggestions for how to produce good coordinates in the first place.

2. How the Assignments are Done

Let us imagine that we begin with a list of 1000 program objects, 50 clean sky postions, and 30 stars suitable for fops. The program objects are in priority order—you'd rather observe the ones at the top of the list than those faint guys near the bottom. We would like to get as many of the program stars on using the fiber cable (which contains 138 fibers), but we need to have at least 9 skys on each configuaton. For good guiding and acquistion, we recommend using 5 fop stars.

The program computes the x and y positions relative for all the objects, skys, and fop stars. It keeps track of which of these are in illegal positions (off the edge of the field of view) using the celestial coordinates of the field center you have provided. This astrometry may be a little different at the telescope, of course, as you may be observing at a slightly different LST and hence differential refraction will have moved objects around a little.

The assignments are first made on the first 138 *legal* objects. (By legal, we mean only that the objects are in the field of view.) The assignments are done ignoring collisions, but always by finding the unassigned fiber nearest in angle. We begin this process by first sorting the objects in this hopper radially. For objects near the edge of the plate there may be only one or two fibers we can assign to them without violating bending constrants on the fibers. As we move in towards the plate center we begin to be able to reach a position for an increasing number of fibers, until near field center we can reach a position with half of the fibers. Thus we start doing the assignments of fibers to objects starting with those with the greatest radius and working our way inwards. Once we get within the central portion of the plate (R=0.25) we ignore the radius and simply continue with the assignments in priority order.

Note that at this point the priorities have not played a very big role— they have determined what items got thrown in the hopper, and they have played a minor role in the assignment of fibers in the center portion of the field, but we could well have had an object of low priority gobble up the only fiber that could be assigned to a high priority object that was merely a little ways further inwards. In practice, this seldom seems to be a problem. In some cases we *may* find that there is no fiber that can be assigned to a star, as all the ones that can reach this location have already been assigned to other objects, but that's life. This procedure continues until we are either out of fibers or out of objects.

In doing the assignments we have so far ignored the resulting collisions: these preliminary assignments probably contain many crossings. We next try to resolve these by lookng first at adjacently assigned fibers. If two fibers touch, we try swaping their assignments, IF by doing so we will remove the collision condition. (In the case of two objects that are too close to each, for instance, no amount of swaping will ever help!) Next we try this swaping more globally, making several passes trying to untangle the twisted net we've woven. Of course, this won't always work: it may be that a fiber is colliding with a parked fiber of the *other* fiber bundle (the blue bundle in this case), or a parked fops fiber; some collisions won't resolve because the objects are too close together. It is also possible to simply have too big a mess to be resolved in this simple manner, but that turns out to seldom be the case: insisting that we assign a fiber that is nearest in angular distance does a lot to prevent collisions.

Once we've made numerous attempts to resolve the tangles, we check to see what collisions are left. In this "verification" pass we first check each fiber to see if it collides with an *unassigned* parked fiber. If so, we simply remove the assignment, as there is nothing we can do to straighten this out. Next, we start with the fiber assigned to the highest priority object and see if it collides with any other fibers. If so, we undo the assignment of the other fiber(s). This may result in your losing five stars that are only slightly lower in priority than the one being considered, but probably not—these other five are likely to be colliding with each other too! We then proceed to the next star down the priority list, and continue unassigning fibers until we have a collision-free set.

Next we put on the required number of skys. First, we see if we can simply sneak any skys on for free—are there any unassigned fibers that can reach a sky position without colliding with anything? We do *not* allow any collisions at this point.[1] We put as many unassigned fibers on as many skys as we can at this point, up to a maximum of the required number of sky positions. (We will come back later and see if we can sneak on any more skys, but that is only after we have used any unassigned fibers on object positions. Afterall, which would you rather observe?)

If we have been unable to sneak on the required number of skys this way we now force the issue. For each fiber (assigned or not) that can reach any sky position, we consider how much damage we would do by that assignment. We consider what would have to be unassigned to make this happen collision-free. In choosing the lesser of evils, the user can specify any of three weighting schemes: a *strong* weighting schme, in which the weight assigned in the inverse of the position in the hopper (i.e., item ten is worth one-tenth of the top item), a *weak* weighting scheme, which is the square root of the *strong* scheme, or *none*, in which all objects are considered of equal weight—at least for resolving collisions.[2] We then assign whatever

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[1]We may want to change this at some point to allow collisions that can be untangled by a simple swap, but it hasn't happened yet.

[2]Note that these weights are used *only* for forcing the issue with the fops and skies.

fiber-sky combination does the least damage, undoing whatever previous assignments are necessary. We then reconsider the question *ab initio* (afterall, the game has changed because of those un-assignments and the previous sky assignment), and continue doing whatever is the least damaging until we are done.

Next we do the same procedure to get the required number of fops on. Can we get our one required fops on? What does the least amount of damage if we have to force the issue? The skys that have been added in the previous step are considered sacred during this procedure and cannot be removed.

At this point we probably still have a number of unassigned fibers. Can we sneak them on *any* of the fiberless objects? We consider the entire list of free objects here, including ones that were originally in the assignment hopper but got bounced out, proceeding in priority order.

Finally, if we have any unassigned fibers, and any unassigned sky positions, we attempt to sneak those on as well. This goes a long ways towards undoing previous sins.

Often a change in the location of field center, will make allow more and/or higher priority objects to be assigned. Therefore there is an an option that allows the user to declare whether or not to tweak the field center in an $n \times n$ grid.

For each center position, the assignment procedure is started from scratch, and sum of the weights of all the assigned objects is computed. For an object with position "i" in the list, **strong** weighting will result in its weight being assigned $1/i$. For **weak** weighting, the weight of the object would be $\sqrt{1/i}$. If the weighting scheme you chose was **none**, then all objects have qual weight. At the end, the field center is changed to the grid point that has the greatest combined weight, as long as the requirements for the number of fops and skys assigned are met.

3. Usage

The input file must begin by specifying nine key-words, one per line. Each key-word ends with a colon and is followed by a "value". In the current scheme of things there should be at most one space between the colon and the value. These words, and the acceptable values, are given below:

Key-words:

FIELD NAME: [$\leq$ 64 character ID]

INPUT EPOCH: (equinox of the input coordinates; must be 1855-2010.)

CURRENT EPOCH: (epoch of the proposed observations, e.g., 1992.251, must be 1991-2000)

SIDEREAL TIME: (LST at mid-exposure, must be 0.00-23.999)

EXPOSURE LENGTH: (Decimal hours expected for exposure, 0.0-10.0)

WAVELENGTH: (Wavelength of spectragraph; either 3200-10000, in which case the units are interpreted as Å, or 0.32-1.0, in which case the units are interpreted as μm.)

CABLE: (LARGE is the only cable currently active)

WEIGHTING: (possible answers are STRONG (default), WEAK, or NONE).

GUIDEWAVE: (wavelength of TV camera, defaults to 6000Å).

The above key-words can be in any order at the top of the file.

After the key-words, we have the list of coordinates. Each coordinate entry consists of a *single line*, and includes the following. The format is fixed.

- Integer ID (4 digits or less). This should be a unique number that allows you to tell the fiber positioner what star you are talking about if you wish to drive the gripper over to that locale. It will also be kept as a seconary identifier when you reduce the data with IRAF. COLS 1-4
- Name (20 characters or less). This name is the principle object identifier; it will be kept with the individual spectrum when you reduce the data with IRAF. COLS 6-25
- RA. This should be specified the usual way, e.g., "02 12 14.123". The leading zeros are not rquired. Since we are reading these numbers in a fixed format, you may include colons (or anything else) where the spaces go. COLS 27-38
- DEC. This should be specified the usual way, e.g., "-01 12 13.21". For positive declinations the plus sign is optinal. The value of the degrees must be between -89 and 89, and the values of the minutes and seconds < 60. The SIGN goes into COL 40; the rest go in COLS 41-51
- CLASS. This is a one letter code that specifies what type of object this is. COL 53. Possible answers are:

C Center. There must be exactly one of these in the file; it is the coordinates of the plate center.

O Object. This is the default if the item is unspecified, and is a normal program object. Currently the maximum number of objects is 2000.

S Sky. Currently the maxium number of sky positions is 10000.

F Field-orientation-probe star (FOPS). Currently the maximum number of FOPS is 10000.

In order to provide some capability for you to document what you are doing, we interpret any line that begins with a pound sign ("#") to denote a comment field. These will be retained in the output file, although not in the place that you stick them (see below). Items with double pounds signs will not be retained; these are used in the output files to denote warning messages.

A sample file appears in Figure 1.

When running **hydraassign** you will be asked for the input file name and the output root name, as well as the number of fops and skys you require. Thus a sample run might look like that of Figure 2. An example of the same data run when we do allow the center to be tweaked can be found in Figure 3.

The output file will very much resemble the input file. However, (a) the comments will all have been collected under the header information, (b) the object code "O" will have been explictly stated for any program object, (c) the ordering will have changed so that all the guide stars and skys will be at the top of the list, followed by all the objects to which fibers could not be assigned, followed by all the objects to which fibers were assigned, and (d) the status will be listed after every object.

This status word contains the fiber number assigned if an assignement was made ("STATUS=266"). Otherwise, the status indicates whether the object was off the edge of the plate ("STATUS=EDGE"),was fine ("STATUS=OK") but it just so happened that no fiber was assigned. Within the two catagories of unassigned and assigned objects, the original ordering is preserved. Thus this output file can be used as an input file for constructing a new configuation, and the process continued until all the objects you really care about have been assigned fibers. In doing this, you may want to change the center slightly to take care of objects on the steps or off the edge. See Figure 4 for an example of the output file from the previous run.

In addition to the output file that contains the assignments, the program also writes everything that is written to the terminal into a log file called **assignmentlog**. New runs

```
FIELD NAME: SMC-1
INPUT EPOCH: 2000.00
CURRENT EPOCH:
SIDEREAL TIME:  1.00
EXPOSURE LENGTH:  3.00
WAVELENGTH: 4350.
CABLE: LARGE
GUIDEWAVE: 6000.
WEIGHTING: WEAK
#0000000011111111112222222222333333333344444444445555
#2345678901234567890123456789012345678901234567890123
FIELD NAME: SMC-1
INPUT EPOCH: 2000.00
CURRENT EPOCH: 2001.75
SIDEREAL TIME: 1.00
EXPOSURE LENGTH: 1.0
WAVELENGTH: 8550.
CABLE: LARGE
GUIDEWAVE: 6000.
WEIGHTING: NONE
   1 Center SMC-1         00 48 45.000 -73 21 45.00 C
8001 Fops012768V=12.00    00 49 09.610 -72 19 01.20 F
8233 Fops059193V=12.57    01 04 25.290 -72 31 18.60 F
8234 Fops066066V=12.57    01 07 29.360 -72 30 45.70 F
8235 Fops051954V=12.58    01 01 44.530 -72 33 53.00 F
8236 Fops002753V=12.58    00 43 14.680 -73 30 13.60 F
8237 Fops006038V=12.58    00 45 47.050 -73 39 54.40 F
9271 Sky-9271             00 52 27.570 -73 17 48.60 S
9272 Sky-9272             00 53 34.074 -73 18  6.71 S
9273 Sky-9273             00 53 35.316 -73 19 20.11 S
1032 020133 11.30 0.4M0 I 00 51 29.680 -73 10 44.30
1033 020612 12.15 0.3K5-M 00 51 37.570 -72 25 59.50
1034 021362 11.94 0.4K5-M 00 51 50.250 -72 05 57.20
1035 021381 11.89 0.4K5-M 00 51 50.460 -72 11 32.20
```

Fig. 1.— Sample input file for **hydraassign**

```
griz%hydraassign
## ----------------------------------------------------------------
##
##      Astroparams Version 3.0 10/05/98
## -----------------------------------------------
WARNING: missing param (X_OFFSET)
##
##      Systemparams Version 3.0 12/23/98
## -----------------------------------------------

WARNING: maximum number of objects allowed is 10000

 Input file name: smc1.in
 Output root name: test2
test2.hydra
 There are  846 fops stars found
 How many fops need to be assigned to fops stars?: 5
 There are  166 objects found
 There are  549 skies found
 How many skies are required?: 9
 Would you like to tweak the center? y or n: n

 Field center=Center SMC-1        00 48 45.000 -73 21 45.00  2000.00 Ag= 179.988
 Assigned:   20/ 166 objs;  14/ 549 skys;  11/ 846 fops;  Total wts=  20.00
```

Fig. 2.— A sample run of **hydraassign**. The user requires 5 fops to be assgined from the sample of 846; the program in fact assigns 11. The user requires 9 skys (from a list of 549) to be assigned; the program succeeds at assigning 11. Of the 166 objects, 20 are assigned. Can we do any better by letting the center vary? See the next example.

```
griz% hydraassign
##  v3.1 FOPS, Large fibers, Small fibers. Proper slit to fiber
##       assignments for Large Fibers and most of the Small fibers.
## ---------------------------------------------------------------
##
##      Astroparams Version 3.0 10/05/98
## ----------------------------------------------
WARNING: missing param (X_OFFSET)
##
##      Systemparams Version 3.0 12/23/98
## ----------------------------------------------

WARNING: maximum number of objects allowed is 10000

 Input file name: smc1.in
 Output root name: test3
test3.hydra
 There are  846 fops stars found
 How many fops need to be assigned to fops stars?: 5
 There are  166 objects found
 There are  549 skies found
 How many skies are required?: 9
 Would you like to tweak the center? y or n: y
 How many grid points per side? (3, 5, 7...) : 3
 How many arcmin per each of the  9 grid points?: 3.0
 Will check a  3x  3 grid with step size  3.000 arcmin

 Field center=Center SMC-1        00 48 03.088 -73 24 45.00  2000.00 Ag= 179.988
 Assigned:   18/ 166 objs;  14/ 549 skys;   9/ 846 fops;  Total wts=  18.00

 Field center=Center SMC-1        00 48 45.000 -73 24 45.00  2000.00 Ag= 179.988
 Assigned:   18/ 166 objs;  16/ 549 skys;   9/ 846 fops;  Total wts=  18.00

 Field center=Center SMC-1        00 49 26.912 -73 24 45.00  2000.00 Ag= 179.988
 Assigned:   18/ 166 objs;  18/ 549 skys;   7/ 846 fops;  Total wts=  18.00

 Field center=Center SMC-1        00 48 03.088 -73 21 45.00  2000.00 Ag= 179.988
 Assigned:   19/ 166 objs;  14/ 549 skys;   9/ 846 fops;  Total wts=  19.00
...
 Field center=Center SMC-1        00 48 45.000 -73 18 45.00  2000.00 Ag= 179.988
 Assigned:   21/ 166 objs;  12/ 549 skys;   6/ 846 fops;  Total wts=  21.00

 Field center=Center SMC-1        00 49 26.912 -73 18 45.00  2000.00 Ag= 179.988
 Assigned:   21/ 166 objs;  10/ 549 skys;  10/ 846 fops;  Total wts=  21.00
 Original center=00 48 45.000 -73 21 45.00 Ag= 179.988 summed weights=     20.00
 Revised center=00 48 03.088 -73 18 45.00 Ag= 179.988 summed weights=     21.00

 Field center=Center SMC-1        00 48 03.088 -73 18 45.00  2000.00 Ag= 179.988
 Assigned:   21/ 166 objs;  10/ 549 skys;   9/ 846 fops;  Total wts=  21.00
```

Fig. 3.— . The same data is now run, allowing the center to be tweaked. At the end 21 out of 166 objects were assigned, with 10 skys and 9 fops.

```
FIELD NAME: SMC-1
INPUT EPOCH: 2000.00
CURRENT EPOCH: 2001.75
SIDEREAL TIME:  1.00
EXPOSURE LENGTH:  1.00
WAVELENGTH: 8550.
CABLE: LARGE
GUIDEWAVE: 6000.
WEIGHTING: NONE
   1 Center SMC-1         00 48 03.088 -73 18 45.00 C  Ag= 179.988
8001 Fops012768V=12.00    00 49 09.610 -72 19 01.20 F  STATUS=EDGE
8002 Fops084202V=12.00    01 33 08.980 -73 25 32.50 F  STATUS=EDGE
8003 Fops077994V=12.00    01 17 53.520 -73 21 12.70 F  STATUS=EDGE
...
8040 Fops009352V=12.14    00 47 50.370 -73 14 22.50 F  STATUS= 144
8048 Fops070978V=12.17    01 10 25.100 -72 15 07.80 F  STATUS=EDGE
...
8049 Fops008983V=12.18    00 47 38.910 -73 22 53.40 F  STATUS= 264
...
9538 Sky-9538             01 10 27.080 -72 20 21.32 S  STATUS=EDGE
9539 Sky-9539             01 09 45.035 -72 37 11.63 S  STATUS=EDGE
9540 Sky-9540             01 06 50.143 -72 43 16.63 S  STATUS=EDGE
...
9541 Sky-9541             01 06 14.241 -72 38 39.43 S  STATUS=EDGE
9542 Sky-9542             01 04 49.315 -72 39 14.87 S  STATUS=EDGE
...
1018 012707 12.40 0.2     00 49 08.230 -73 14 15.50 O  STATUS= 103
1019 013472 10.88 0.4K0-K 00 49 24.530 -73 18 13.50 O  STATUS=  74
1020 013740 12.51 0.3     00 49 30.340 -73 26 49.90 O  STATUS=  30
1021 013951 12.07 0.3     00 49 34.420 -73 14 09.90 O  STATUS= 101
1022 015020 12.03 0.3     00 49 57.170 -73 37 39.80 O  STATUS=  19
1023 015217 13.51 0.1     00 50 00.750 -73 10 51.40 O  STATUS= 105
1024 015510 11.64 0.4M0 I 00 50 06.420 -73 28 11.10 O  STATUS=  34
1026 017684 13.73-1.6     00 50 47.640 -73 24 16.40 O  STATUS=  53
...
```

Fig. 4.— Output file from previous input file.

of the program will simply be added at the end of this file.

4. Geometry and Astrometry

The focal plane of the instrument consists of a plate which, when the instrument is in use, is warped via a vacuum to approximate the curved focal surface.

The following are the steps that we go through in determining where on the focal plane to plunk down a fiber to assure it is where it is supposed to be.

- Precess coordinates to current epoch. This removes the rotation that would otherwise be introduced.
- Remove the effects of differential refraction across the field. This relies upon the spectrograph wavelength for the object and sky fibers, and for the GUIDEWAVE wavelength for the fops. We also adopt a ground temperature typical for nighttime on Cerro Tololo based upon the fraction on the "current epoch".
- Conver to tangent-plane coordinates. This removes the projection effects of curved lines of declination. These tangent-plane coordinates are usually referred to as η (Eta) and ξ (Xi).
- Do the transformtion to location within the curved focal plane using the plate scale and (possibly) higher-order terms.
- Apply a correction to tell us where to place the fiber in the flat x-y plane that is tangent to the curved focal plane.

5. Appendix: How to Make Decent Coordiantes

The success of you run depends entirely upon coming to the telescope with accurate positions: if there is a relative offset between your fops stars and your program objects of 0.5" you are likely to lose a significant amount of the light even using 2 arcsec fibers.

It is particularly important that your fops and program objects are based upon the same sources—i.e., if however you've gotten coordinates for your program objects, you need to have generated coordinates for the fops the same way. Here are some suggested resources and techniques.

If your objects are releatively bright stars ($V < 20$) chances are good that they already have good astrometry from the US Naval Observatory. See

http://ftp.nofs.navy.mil/projects/pmm/readme.html

Another pleasent way to get accurate astrometry is to use the STScI Digitized Sky Survey images, but care must be taken to use the "good kind" (suitable for Phase II proposals) and not the old scans of the older material. I usually extract a 60'x60 section using the Web interface at:

http://archive.stsci.edu/dss/dss_form_phase2.html

Once you've gotten good x and y positions from the frame, you can use the header information to convert these to RA and DEC using the STSDAS routine "xy2rd". First, run "makewcs" on your image (lmc.fits). With your x and y positions in a file "lmcxy", you can use a little script to produce RAs and DECs:

```
list="lmcxy"
while (fscan (list,x,y) !=EOF) {
xy2rd ("lmc.fits", x, y, >> "lmcrd")
}
```

Finally, there are tools with IRAF to help you to astrometrically calibrate CCD frames. Look at IRAF "tfinder", and it's documentation; this is available as an add-on external package.