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A Comparison of Large All-Sky Catalogs

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Abstract. Accurate positions are need to compare observations of objects made at various wavelengths, such as are to be found in the Virtual Observatory. New instruments for ground-based observing, such as multi-fiber spectrographs, also need very accurate positions for objects fainter than those already catalogued. Recent large catalogs have revolutionized our ability to do astrometry with CCD images. The recently published FITS World Coordinate System standard has provided a standard way of parameterizing that astrometry, and the WCSTools and SExtractor software packages allow the automation of the "plate-fitting" process. As part of a survey to be conducted with one of these new spectrographs, we have amassed 1728 15 by 30 arcminute CCD images of a portion of the northern sky. After matching image point sources to objects in each of the catalogs and fitting world coordinate systems to them using the IMWCS program, we find mean residuals between observed and catalog star positions of between 0.09 and 0.25 arcseconds for the latest catalogs.

1. Introduction

In the last few years, several motivations for acquiring sub-arcsecond astrometry of faint astronomical sources have arisen. Surveys and studies of specific objects at radio and x-ray wavelengths require exact optical or infrared positions to identify optical counterparts. Small aperture spectroscopes such as the 300-fiber MMT Hectospec require input positions better than a half arcsecond. The usual method of acquiring positions for faint, uncatalogued objects is to match the brighter stars in a CCD image to one of the deep catalogs which have been developed over the past 20 years by the Space Telescope Science Institute, the U.S. Naval Observatory, and the 2 Micron All Sky Survey. Table 1 shows the history of those large catalogs. At the same time, standards and software for associating image pixels with sky positions as world coordinate systems have been developed, culminating in two papers (Greisen & Calabretta 2002, Calabretta & Greisen 2002) and a software package which utilizes Calabretta's WCSLIB with real images (Mink 1997, Mink 1999, Mink 2002).

As more and more optical images were matched to catalogs, the question of the accuracy of the positions of objects in the catalogs arose. We set out to compare how well various catalogs fit a large set of images.

Table 1. Growing Astronomical Catalogs

Year	Catalog	Number of Sources	Reference
1989	HST Guide Star Catalog (GSC I)	25,541,952	Lasker et al. 1990
1996	USNO-A1.0 Catalog	488,006,860	Monet 1996
1998	USNO-A2.0 Catalog	526,280,881	Monet 1998
2001	GSC II Catalog (2.2.01)	998,402,801	McLean et al. 2000
2002	USNO-B1.0 Catalog	1,036,366,767	Monet et al. 2003
2003	2MASS Point Source Catalog	470,992,970	Cutri et al. 2003
2003	USNO UCAC2 Catalog	48,366,996	Zacharias et al. 2000

2. Data and Analysis

As part of the CfA Century Survey of galaxies (Geller et al. 1997), 1728 15 by 30 arcminute CCD images of a portion of the northern sky over the north galactic pole were taken as 216 exposures by the 8-detector, one-degree-square MOSAIC camera (Muller et al. 1998) on the KPNO 0.9 m telescope in 1998 December and 1999 January and processed as described in Brown et al. 2001. A correction was made for distortion across the wide field and a world coordinate system was fit to objects in the images found by SExtractor (Bertin & Arnouts 1998) using WCSTools and the GSC-I catalog. The resulting image catalogs, with image coordinates and approximate right ascension and declination, became the raw data for our study.

The uniformity of the images and the fact that they cover a portion of the sky well away from the dense star fields of the galactic plain made them ideal for automatic star matching. Unix shell scripts written for each catalog set up an initial FITS header for each of the 1728 images with the center being the mean position of the objects found in that image.

The WCSTools imwcs program was then run on each image. The IMWCS program fits the same number of brightest catalog objects and brightest image objects limited by whichever there were fewer of; with these wide field images, the number of catalog objects in the field was usually the limit. The IMWCS program fit all eight parameters of the FITS WCS tangent plane projection to all of the catalog-image matches in the field. The program made three additional iterations per image following an intial fit. The second fit used the refined parameters which might have changed the position and size of the catalog section to be matched. In the two final passes, the tolerance in the catalog-image match was reduced by half each time to eliminate both bad matches and objects whose catalog positions did not match their actual postions. The goodness of a fit for an image is judged by the mean radial offset between the position of the objects in the image mapped to sky coordinates through the fit world coordinate system and the catalog position of the closest object, which is almost always within one arcsecond.

3. Results

The means of the individual image offsets were used to compare how well each catalog matched the sky as captured by our 1728 CCD images. The GSC-I was used as a baseline, despite the fact that it matched 25 or more stars in

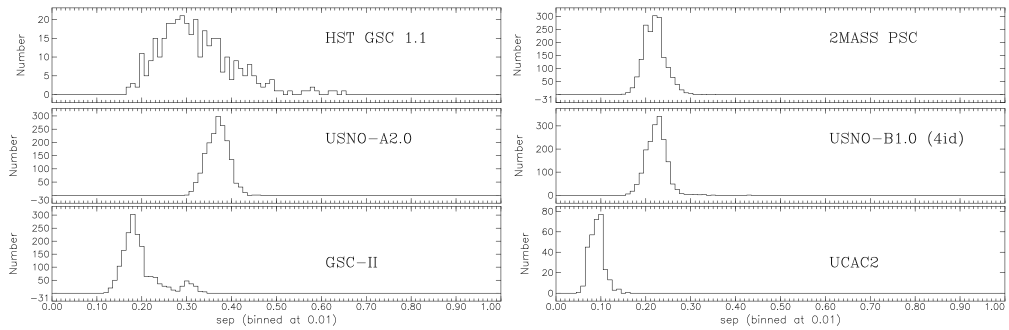

Figure 1. Distribution of image-catalog radial offsets.

only 353 of the 1728 images. Figure 1 shows the distribution of mean Catalog-Image positions in arcseconds. Table 2 shows how many catalog stars were found in each images as a range and an average, how many catalog stars were fit to image stars, as a range and an average for each catalog and the range of mean (Observed-Catalog) radial offsets per image, and the mean and standard deviation of that mean for the entire data set.

Table 2. Fits of Various Catalogs to 1728 Images.

Catalog	Catalog Stars		Matches fit		Image-Catalog (arcsec)	
	Range	Mean	Range	Mean	Range	Mean(Sigma)
GSC-I	26-61	35.78	25-64	34.16	0.168-0.654	0.321(0.085)
USNO-A2.0	119-454	258.52	78-353	189.10	0.301-0.457	0.368(0.024)
GSC-II	90-752	226.73	87-378	179.16	0.123-0.343	0.196(0.043)
2MASS PSC	93-365	171.06	86-331	153.26	0.154-0.347	0.220(0.024)
B1.0/id=2	136-1125	586.50	51-661	418.47	0.182-0.523	0.267(0.030)
B1.0/id=3	136-957	528.38	62-653	382.16	0.181-0.479	0.251(0.029)
B1.0/id=4	136-654	365.13	116-555	309.98	0.155-0.430	0.223(0.023)
B1.0/id=5	109-409	227.89	98-375	205.14	0.136-0.326	0.192(0.021)
UCAC2	40-72	51.52	40-69	48.80	0.054-0.159	0.091(0.015)

The GSC-I based on plates from the 1980's does better than the USNO-A2.0 which is based on plates from the 1950's, probably due to the motions of stars in the intervening years, though the shorter exposures of the GSC-I may also have given better centers. The more recent GSC-II, 2MASS PSC, and USNO-B1.0 catalogs all are based on the Tycho-2 astrometric reference catalog (Hog, et al. 2000), and give similar results. When the USNO-B1.0 gave worse results than expected, it was filtered by the number of plates (POSS I red and blue, POSS II red and blue, and N) on which the object was found. Thus the most recent catalogs all cluster around 0.2 arcsecond mean offset. Only 303 images were fit to the recently-released UCAC2 catalog which covers our field, but it is incomplete, so the automatic matching algorithm does not work perfectly. The mean offset was 0.1 arcsecond, tightly clustered as the standard deviation and Figure 1 show, half that of the other catalogs. This shows that detector nonlinearity is not an issue above 0.1 arcsecond, at least for these CCDs, and that there is room for improvement in the astrometry of current deep all sky catalogs.

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