SSA Applications of the PS1 AP Catalog

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ABSTRACT

The Pan-STARRS PS1 Astrometry and Photometry (AP) Catalog is described by [1] in these Proceedings. This discussion focuses on the Space Situational Awareness (SSA) applications of the astrometric accuracy of this catalog, and how the PS1 AP survey can meet these Requirements.

1. INTRODUCTION

The PS1 Survey, described more fully in [1], is expected to produce a catalog of astrometric data of unprecedented accuracy and depth. It will be useful for many scientific and functional tasks, and it will enable new SSA opportunities based on enhanced metric accuracy. One meter at the distance of the geo-synchronous orbit corresponds to 5 milliarcseconds of angular measure. The Requirements for the PS1 AP catalog are for an astrometric accuracy of 10 milliarcseconds, so this means that the error associated with a single catalog star corresponds to 2 meters at GEO. As shown by [2], this astrometric accuracy leads to metric observations of satellites clearly showing velocity changes of 1 meter/second. The SSA discussion presented here is an overview at the unclassified level.

2. SPACE SITUATIONAL AWARENESS

The traditional usage for high-accuracy star catalogs is in the area of in-frame metrics. The PS1 AP catalog should go faint enough (red magnitude of 20 or fainter) to guarantee that many catalog stars will be in the field of view of almost every SSA sensor. These catalog stars provide a mapping for every frame into the system of (α,δ) with an accuracy of better than 10 milliarcseconds, and provide a photometric calibration with an accuracy of better than 5%. This enables both metric and photometric data to be taken from the same image, and enables SSA observations during many classes of non-photometric sky conditions. The five colors in the PS1 AP catalog enable the correction of the catalog magnitudes into the system of the SSA sensor by means of a color term computed for each star.

The other area where high-accuracy metrics are important is obtaining attitude knowledge for a spacecraft. In many cases, particularly below the geo-synchronous orbit, the pointing accuracy for sensors and systems mounted on spacecraft is limited by the real-time knowledge of the attitude. Spacecraft position is usually less of an issue because high-accuracy GPS receivers have been space-qualified. High-accuracy star catalogs such as the PS1 AP catalog are necessary for improved attitude knowledge, but a new generation of star trackers will need to be developed to take full advantage of them.

3. THE ASTROMETRY CLIENT

Astrometric processing of the PS1 data is done in two places, the Image Processing Pipeline (IPP) and the Astrometry Client (AC). This design was chosen so as to minimize the impact of enhanced astrometric processing on the PS1 design. Centroiding is done in the IPP, and this is the only instance where astrometric processing involves processing of the image pixels. The remainder of the astrometric processing is done by the AC and involves computing mean positions for all objects in the catalog as well as secular changes in the positions of some objects resulting from proper motion, parallax, and perturbations caused by unseen companions.

The IPP performs many image processing tasks, but as far as astrometry is concerned the most important is computing the image centroid. Whereas there is a great deal of astrometric heritage for the processing of data from traditional charge coupled devices (CCDs), there is very little heritage for the processing of data from the orthogonal transfer CCDs (OTCCDs) that PS1 will use. In advance of the acquisition of real PS1 data, all that can be done is to prepare various centroiding algorithms for insertion into the IPP. Of particular interest are the traditional least squares fit to a circular Gaussian function and the centroids computed in the fit to the observed point spread function (PSF). Should neither of these perform according to expectation, a new algorithm will be developed. Fortunately, the design of the IPP supports the insertion (or replacement) of new modules with a minimal impact on the rest of the IPP.

The AC is responsible for the compilation of catalogs from the ensemble of all centroids computed for all objects detected on all frames. In the current design, the AC is a stand-alone computer cluster whose tasks are to accumulate the astrometric portion of the IPP output, to store these data for at least one year, and to compile the astrometric catalogs on an ongoing basis. When the PS1 Published Science Products Subsystem (PSPS) is available, the AC may be reconfigured to use a "crawler" in the PSPS database to replace the IPP output capture and storage functions.

Traditionally, the algorithm for astrometric catalog compilation is based on Block Adjustment (BA), and this has been implemented in the current version of the AC. This technique assumes that only a few free parameters are needed to describe the astrometric transformation of each frame, and that these should be computed from a single solution that minimizes the residuals from all frames. In most instances, BA is a relatively simple operation applied to a few tens or hundreds of frames. For PS1, the global minimization of residuals will need to treat tens or hundreds of thousands of frames in a single solution. The inversion of large matrices is a subtle art, and various compromises are needed to keep the numerical processing under control. The initial design uses the algorithm presented in [3].

A curious attribute of the AC processing is that there is no universal agreement as to the quantity that should be minimized by the least squares solution. One can argue that χ^2 should be computed from the residuals between the observations and an external reference catalog. On the other hand, one could argue that χ^2 should minimize the residuals between the individual observations and the catalog mean positions. Because of this, the formalism developed by [4] has been adopted.

$$\chi^2 = \Sigma_m \Sigma_f \Sigma_s w_m((\alpha_{fs} - \alpha_m)^2 \cos(\delta)^2 + (\delta_{fs} - \delta_m)^2)$$

The sums over frames (*f*) and stars (*s*) are as usual. The difference is to include each of several different error models (*m*) with an appropriate weight (w_m) that can be changed between solutions or during the minimization process. Currently, proposed models include traditional optical catalogs such as *Hipparcos*, *Tycho-2*, *UCAC*, *USNO-B*, and *2MASS*; radio catalogs such as *ICRF* and *RORF*; and the internal measures of the same stars taken on different frames. A simulator+solver has been developed, and is being used to understand the impact of the various statistical models, and to characterize the behavior of solutions with tens or even hundreds of thousands of free parameters. (According to the current PS1 cadence simulator, PS1 will take about 100,000 exposures per year.) At the current level of algorithm development and processing power, it takes about 2 hours to solve a year's worth of PS1 data in a single color.

Already, the AC simulator has demonstrated the difficulty of removing systematic errors from the astrometric solution. Whereas most of the scientific applications of the PS1 AP catalog are not overly concerned with the absolute astrometric accuracy (i.e., the fidelity of the catalog coordinates (α,δ) to the system of coordinates commonly referred to as *J2000*), the SSA applications are quite sensitive to this calibration because of the need for accurate orbital solutions. The formalism adopted for the AC allows for two different solution algorithms, and these can be compared to sense and remove systematic errors. The first approach is to compute the astrometric transformation between each PS1 frame and the reference catalog, and to use the BA solution to minimize the residuals averaged over the ensemble of frames. The second approach is to use the very sparse but very accurate radio catalogs to calibrate the PS1 frames that contain these objects, and to use BA to build the catalog between the calibrated frames in an iterative manner. Both approaches will be tried, but the optimal choice depends on the as yet unknown error distribution of PS1 data.

4. CONCLUSIONS

The AC hardware has been purchased and delivered, and the initial design and build of the software has been completed. A simulator is being used to debug the software as well as to learn about the performance of the algorithms under various models for the error distribution. The next big step will be the acquisition and processing of PS1 data during the commissioning phase. As noted above, there is minimal heritage in processing of OTCCD data, and the camera and telescope stability have yet to be characterized. A preliminary version of the AC is available, and frantic developments are expected in the very near future. The development of the AC is a team effort, and the presenting author would like to acknowledge the very significant contributions made by many members of the PS Team.

4. REFERENCES

1. Chambers, K. et al., *AMOS Technical Conference Proceedings*, 2006.
2. Monet, D. et al., *AMOS Technical Conference Proceedings*, 2005.
3. Press, W. et al., *Numerical Recipes in FORTRAN*, Cambridge University Press, 1992.
4. McCallon, H. and Cutri, R., *http://irsa.ipac.caltech.edu/Missions/2mass.html*.