Data Reduction Algorithm for Optical Wide Field Patrol(OWL)

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ABSTRACT

OWL(Optical Wide-field Patrol) has a detector system which has the chopper which consist of 4 blades in front of the CCD camera to acquire efficiently the position and time information of moving objects such as artificial satellites. Using this system, it is possible to get more position data by splitting the streaks of the moving object into many pieces with fast rotating blades during tracking. At the same time, the time data of the rotating chopper can be acquired by the time tagger connected to the photo diode. In order to derive the orbits of the targets, we need a sequential data reduction procedure including the calculation of WCS(World Coordinate System) solution to transform the positions into celestial coordinate systems, and the combination of the time data from the time tagger and the position data. We present such a data reduction procedure and the preliminary results after applying this procedure to the observation images.

1. OWL DETECTOR SUBSYSTEM

The OWL (Optical Wide-field Patrol) Detector Subsystem (DT system) is composed of a CCD camera, a filter wheel, a chopper and a time tagger(Fig.1). Each part is explained in the following:

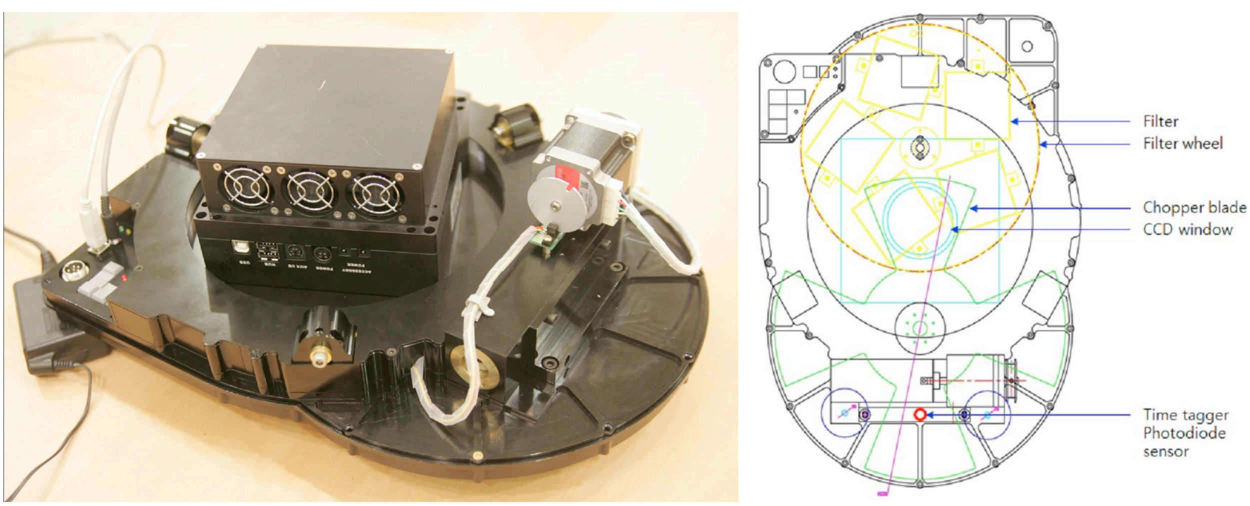

Fig. 1. OWL detector subsystem(DT system). The time tagger is not shown in this picture.

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i. **Filter Wheel.** The OWL filter wheel holds 4 filters of B, V, R and C (Clear).
ii. **CCD Camera.** Finger Lake Instrument PL16803 CCD camera with a sensor chip of 4096×4096 array of 9μm-sized pixels is selected for OWL image acquisition.
iii. **Chopper.** The chopper is used to cut the trail of a moving object on the image into multiple streaks. It has 4 rotating blades which intersect the light rays from the target into the CCD.
iv. **Time Tagger.** The chopper open/close status is recorded with the time using the time tagger. The time tagger is composed of a photodiode, connected to a small box which encloses a simple micro processor.

2. OWL OBSERVATION

The chopper rotates and splits the trail of moving object such as artificial satellite into many streaks, during a single exposure (Fig.2). Time log for each open/close status of the chopper blade, is recorded by the time tagger, which has a photodiode located in front of the chopper. The combination of CCD, chopper and time tagger can produce a large number of positional & time data points through a single exposure.

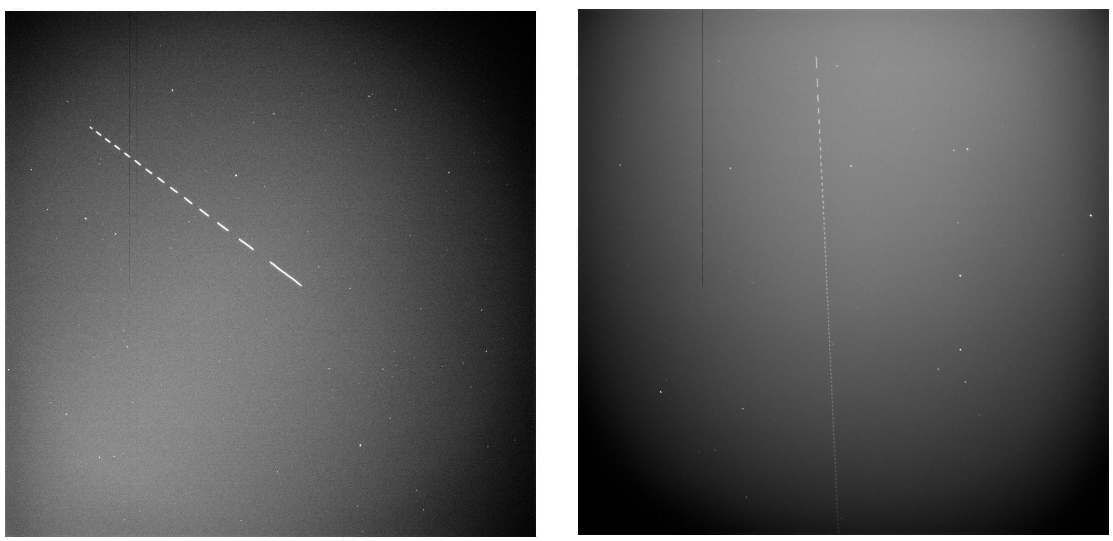

Fig. 2. Examples of OWL observation image. Left: Image of H-2A, taken at Dec 04, 2012 $09^h:39^m$ (UTC), with 1.27 seconds of exposure and 25fps of chopper speed. Right: Image of MOZAYES 5, taken at Mar 21, 2013 $11^h:24^m$ (UTC), with 2.65 seconds of exposure and 50fps of chopper speed.

OWL observation is done using robotic telescopes in many short traces a fast moving targets.

3. OWL IMAGE DATA REDUCTION FLOW

OWL data reduction is performed at observation site automatically in real time, and data reduction flow is given as follows (Fig.3).

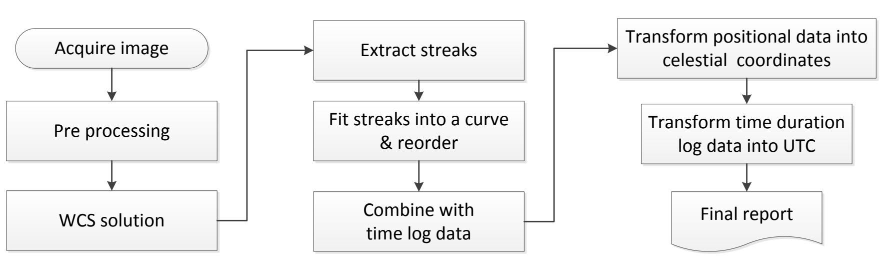

Fig. 3. The flow of OWL image data reduction.

4. WCS SOLUTION CALCULATION

World Coordinate System (WCS) ([3] & [4]) can be obtained from determining coordinate transformation coefficients between the position coordinates of the objects on an OWL observation image and their corresponding celestial coordinates on the sky. Tehy are calculated via comparing, matching and mapping stellar objects on the image and those from published catalogs like GSC catalogs ([6]).

Although generally “WCSTools ([7])” software is being used for this job, it is not so a good solution for OWL images for the case of very short exposure time less than 10 seconds, resulting in insufficient number of stellar objects detected on the image. Instead, “Triangle Pattern Matching” algorithm ([5]) is applied using CCXYMATCH and CCMAP task in IRAF ([9]) package.

Table 1. Comparison between WCSTools and OWL method for WCS solution calculation.

WCSTools	**IRAF CCXYMATCH & CCMAP**
Uses Amoeba algorithm (downhill simplex).	**Uses triangle pattern matching algorithm.**
Needs as many stars as possible.	**Theoretically only 3 stars are sufficient.**
Needs an initial set of coefficient values.	**No initial values are needed.**
Needs the preliminary information about the observation image to make the initial values.	
The results are very sensitive to the initial values. Sometimes it makes wrong solutions corresponding local minima of chi-squares.	The success rate depends on the number of reference stars from the catalog
OWL observation image includes not only the background stars but also the streaks of moving targets. So these have to be removed first.	

To exclude the streaks from all detected objects using SExtractor ([1],[2]), the shape parameter factors of star/galaxy classification and ellipticity are used. Comparison is repeated with varying number of reference stars (Fig.4).

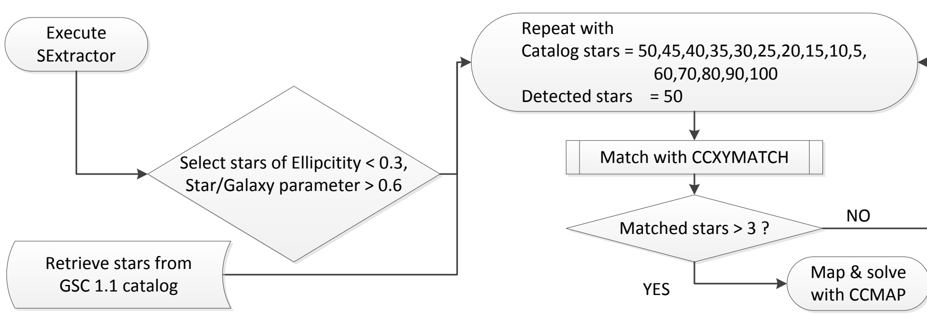

Fig. 4. The flow of WCS solution calculation.

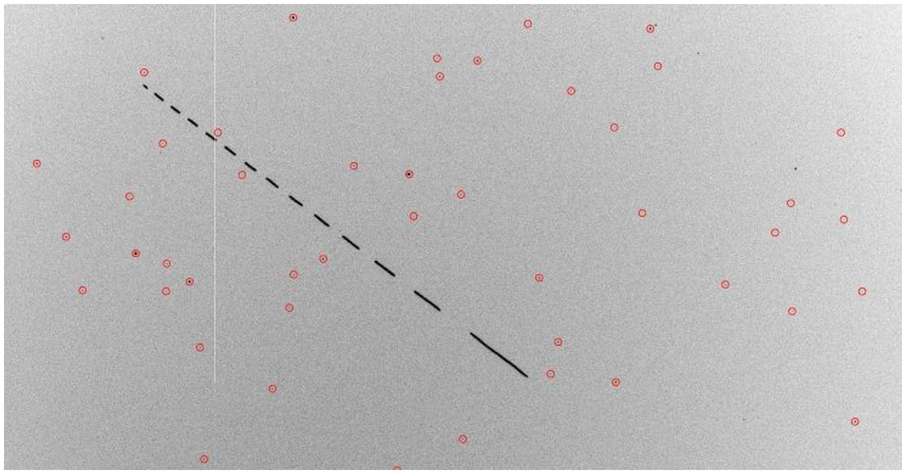

Fig.5. Background stars (red circles) after excluding streaks of the moving target.

5. STREAK DETECTION

The streaks of moving targets can be extracted from SExtractor ([1] & [2]) results. SExtractor produces not only the basic information of positon and brightness of the objects, but also the information of the rectangular area containing the objects on the image such as Xmin, Xmax, Ymin, Ymax , the position angle of the objects, and as mentioned previously, the shape parameters including ellipticity and star/galaxy parameter ([1] & [2]). Using these, it is possible to extract streak-like objects and the information (length) of them (Fig. 6).

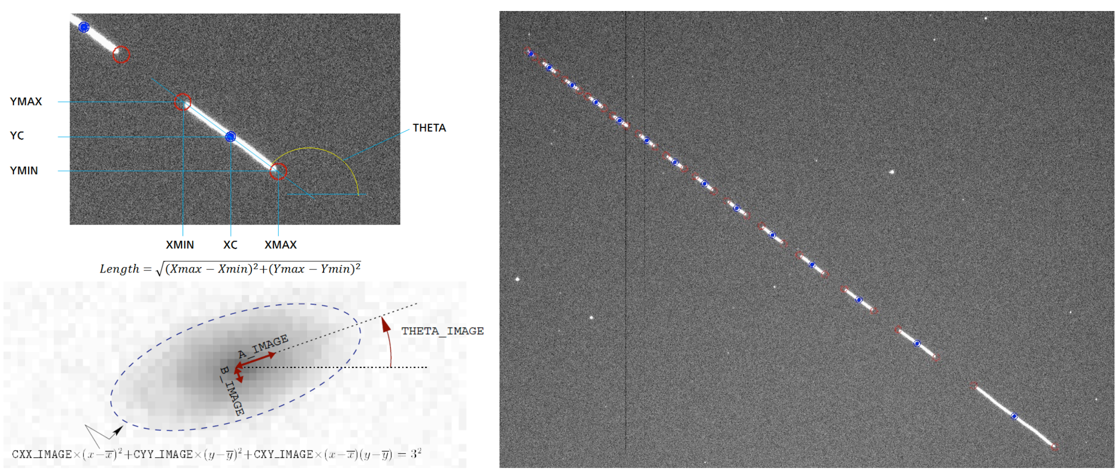

Fig.6. Left: Shape parameters from SExtractor results. Right: Streaks found from the image using these information.

After extracting streaks, the step of grouping and reordering of them along the line of movement is required. This is done by fitting them to a line. In doing this, fitting using simple polynomial is dangerous because the curve can diverge at the both and of it. So, normalizing and fitting to a Legendre polynomial curve ([8]). The product of ellipticity and length of a streak is used as the weight. The sample results are shown in Fig. 7.

6. COMBINING TIME LOG & STREAK POSITION

This is the step of matching the positional data and the time log data acquired using chopper and time tagger. The ratios (L/D) of lengths (L) of each streaks and the durations (D) of the exposures of them are expected to be constant. So, varying and finding the best relative offset between the sequences of L and D which makes the deviation of the ratio is the main idea of this step (Fig. 8).

In other words,

$$\frac{L1}{D1} = \frac{L2}{D2} = \frac{L3}{D3} = \cdots = Constant.$$

$$\frac{\sigma_{L/D}}{\overline{L/D}} \; should\ be\ minimum.$$

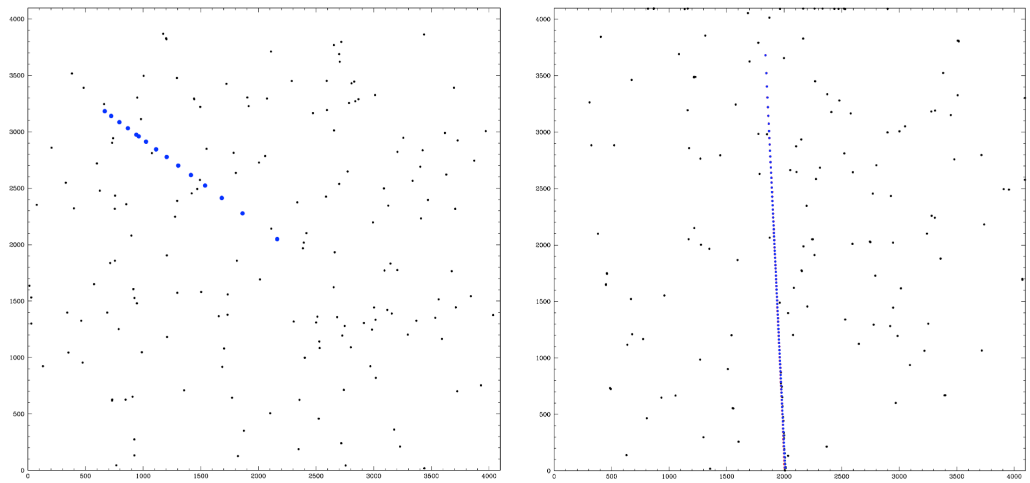

Fig.7. Center positions of the streaks extracted and aligned.

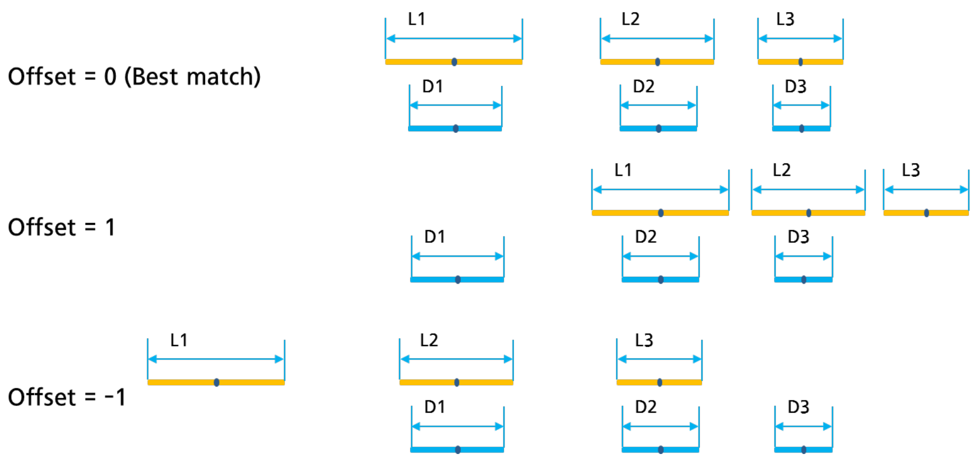

Fig.8. Concept of streak & time log matching.

7. CONCLUSION

OWL is an optical observation system for monitoring moving objects in the sky with a fast slewing & pointing mechanism, and a uniquely designed detector unit for maximizing the performance of acquiring positional and time data in relatively sort exposure time. We performed test observations on several clear nights, and took some good images and clean time log data for developing and testing the software algorithm of data reduction. These provided useful information for preparing future observations. By using the algorithm explained in this paper and good quality image & time data, the basic input data can be produced for efficiently determining the orbit of moving objects, such as artificial satellites and space debris.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

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