ALGORITHMS FOR THE OPTICAL DETECTION OF SPACE DEBRIS OBJECTS

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ABSTRACT

Debris objects are searched for with various systems on ground and in space. Optical observations contribute significantly to the knowledge of the space debris environment. The images that are taken during optical observations are nowadays usually provided in a digital form, e.g. by the use of a CCD-camera. The detection of the debris objects on the images crucially depends on the algorithms used. This paper gives an overview over the algorithms that have been proposed for or are used with different systems.

The algorithms depend on the used observation strategies, which determine the representation of the objects on the images, e.g. whether the debris objects and the stars appear as points or as streaks. Also, if there is more than one image frame available for a specific debris object within a given time interval, the algorithms can make use of a combination of these frames.

The main task of the algorithms is the discrimination between the debris objects, the stars and artefacts. The latter group includes e.g. defective pixels and cosmic ray events, which may lead to unwanted traces on the images. Different algorithms are presented that try to cope with these problems.

Specific problems arise, if the debris objects are faint. In this case, the main problem consists in extracting the signal of the faint debris object from the noise of the background. As there is the possibility that this only succeeds for parts of the trace of the debris object, the resulting trace may appear to be discontinuous on the image. The algorithms have to cope with this situation as well.

1. INTRODUCTION

The algorithms that are presented in this paper are not limited to the search for space debris objects. Typically, the objects of interest that can be detected with these algorithms are (possibly slowly) moving with respect to the stars. They may be e.g. debris objects, Near Earth Asteroids or active satellites.

Three different kinds of objects can be distinguished on the acquired exposures:

- stars
- the objects of interest
- artefacts (e.g. hot or dead pixels, cosmic ray events)

It is one of the main tasks of the processing algorithms, to distinguish between these groups.

The objects of interest on an image are typically represented as points or streaks. The same holds for the stars. The shape depends on

- the observation strategy (e.g. sidereal tracking, ephemeris tracking of the object of interest, staring (i.e. no tracking at all)),
- the exposure time,
- the relative angular velocity of the objects of interest with respect to the stars.

1.1. Typical CCD Images

Some typical images are shown in the following figures. Fig. 1 shows a point-like satellite between point-like stars. This type of image is obtained, when the object of interest is moving very slowly with respect to the stars and sidereal tracking or tracking of the object of interest is applied (which do not differ significantly in this case, as apparent velocity of both in the Earth-fixed system is nearly the same), or when the exposure time is very short. With short exposure times, all three tracking methods result in nearly the same images.

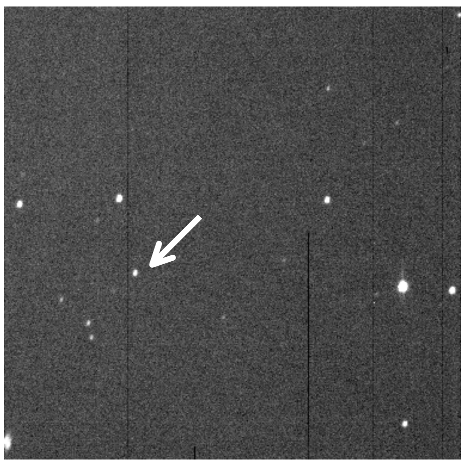

Figure 1. Satellite Integral, Cospar nr. 02048A (see arrow, subframe of an exposure taken on March 3, 2005, at the Zimmerwald Observatory).

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In Fig. 2, a point-like satellite between streak-like stars can be seen. This type of image can only result, when the object of interest is moving fast with respect to the stars and the telescope is tracking the object. The length of the star trails depends on the exposure time and the relative velocity of the object of interest.

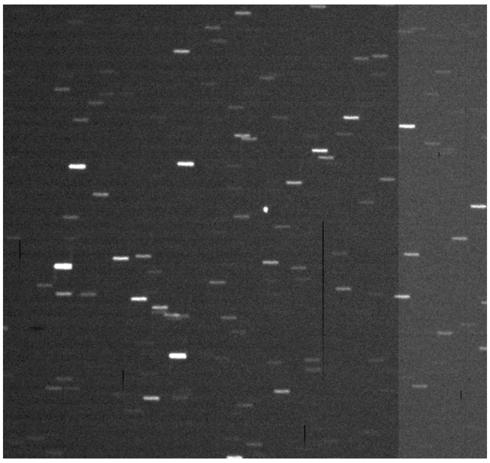

Figure 2. Satellite Intelsat 4A-F6, Cospar nr. 78035A (subframe of an exposure taken on February 8, 2005, at the Zimmerwald Observatory).

Fig. 3 shows a streak-like unknown object between point-like stars. This type of image can only result, when the object of interest is moving fast with respect to the stars. For short exposure times, all three mentioned tracking methods lead to this type of image, for longer exposure times only the sidereal tracking. The length of the trail of the object of interest depends on the exposure time and the relative velocity of the object.

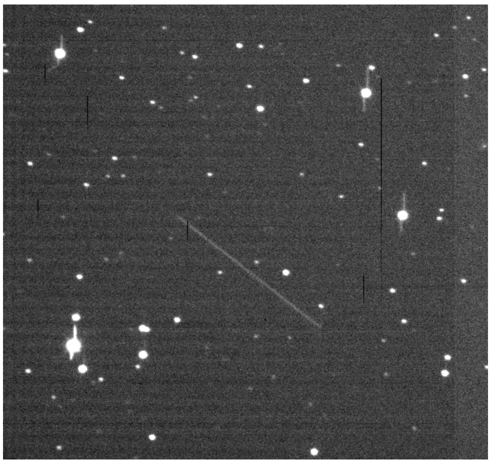

Figure 3. Unknown object (subframe of an exposure taken on February 8, 2005, at the Zimmerwald Observatory).

These are the most common types of images, but other types exist as well (e.g. images where both groups, the stars and the objects of interest, are streak-like objects).

2. IDENTIFYING THE OBJECTS OF INTEREST BETWEEN THE STARS

One of the tasks for the object detection algorithms is to find the objects of interest between the stars. This can be achieved with different methods. Some of them can be applied to single exposures, while others need a series of exposures of the same star region.

2.1. Use of a Star Catalogue

A star catalogue can be used to identify those pixels that belong to stars (up to a given magnitude). These pixels can then be masked, and the remaining illuminated pixels belong to the object of interest, see Fig. 4, where the satellite can be identified easily in the center. Please note, that fainter stars are still visible. Depending on the magnitude of the object of interest, the limiting magnitude for the star mask has to be adapted.

As there might be some unwanted constraints (e.g. the pointing of the telescope or the positions in the star catalogue are not known exactly, or the tracking is not done exactly), it is recommended to expand the mask of a star with a border of one or two pixels. Of course, when the object of interest accidentally coincides with masked pixels, it cannot be found. Therefore the mask should not cover a large part of the frame.

If due to the limiting magnitude of the star catalogue fainter stars are still visible on the masked image, a relatively high threshold is needed to detect the object of interest. Then, no faint objects can be found.

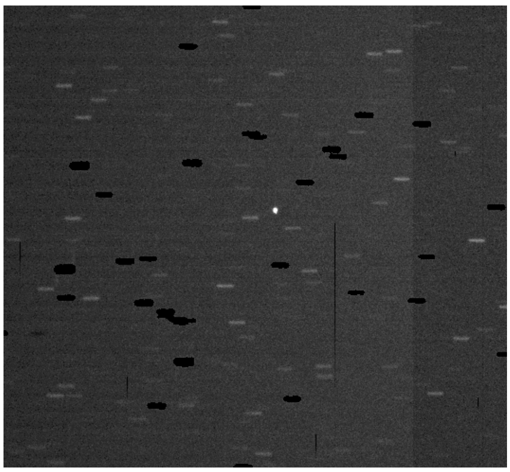

Figure 4. Masking of the brightest stars (taken from a star catalogue) applied to the image of Fig. 2.

A disadvantage of this method is the comparably extensive computing effort to transform the information of the catalogue (e.g. star positions in RA and Dec) into the pixel coordinates. For this, information on the pointing of the telescope and the tracking method is needed. Also, incomplete catalogues can lead to problems.

2.2. Use of Object Characteristics

If the characteristics of the stars and other objects are different (e.g. their shape differs), this can be used to distinguish between them. Two approaches can be followed. The first kind of algorithms detect all connected bright pixels and analyse their properties. Based on these properties, a decision is made, to which of the possible classes the connected pixels belong (e.g. points or streaks). The second kind of algorithms directly find objects of a specific shape. An example is the Hough algorithm (Leavers, 1992), that may be used to find streaks directly.

Methods that use the object characteristics to distinguish between stars and objects of interest can be applied to single exposures.

2.3. Use of Median Image for Mask

If several images from the same star region are available, a median image can be computed, where the objects that move with respect to the stars are eliminated, and only the stars remain. From this image, a mask can be generated which is then applied to the original images. To cope with exposures that are slightly shifted against each other, the masks of the stars should be enlarged by e.g. one or two pixels. In (Schildknecht, 1995) a description of this technique can be found.

Compared to building a mask from a star catalogue, this method provides the advantage, that for all stars on the exposures a mask of the needed shape (e.g. point-like or streak-like) is generated automatically. No explicit information on the pointing of the telescope or the tracking method is needed. All stars that are visible on the exposure are treated, regardless of whether they are in a star catalogue or not. However, this method can only be applied if several images of the same star region are available.

2.4. Use of Median Image for Subtraction

Instead of being used for the construction of a mask, the median image can also be subtracted directly from the original images. However, it has to be kept in mind, that the pixel values for the stars and other objects and for the background vary on different exposures even if the exposure time is the same, so the result is not simply zero.

If only two images are available, they can also be subtracted directly from each other. However, in this case the processing noise gets worse, which is especially crucial in the case of faint objects. Also, cosmic ray events of the subtracted images are not eliminated, unlike to the case of the median image (see section 3).

3. COSMIC RAY EVENTS

Energetic particles from cosmic ray events or from local radioactive decay may lead to charges in the CCD pixels (called "cosmics", that can be misinterpreted as being caused by a real object. In Fig. 5, some examples of cosmics are shown. The processing algorithms have to identify and eliminate the cosmics, which is not a simple task, as some of the characteristics of the cosmics are the same as the characteristics of the objects of interest. Both are usually not on the same place on subsequent exposures, and both might have the same pixel size.

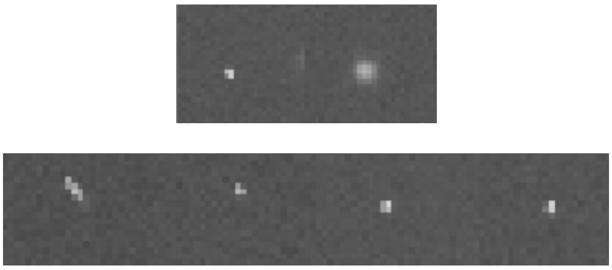

Figure 5. Cosmics as seen on exposures from the ESASDT at the Tenerife Observatory (the upper right object is a faint geostationary debris object shown for comparison).

3.1. Use of Cosmic Ray Characteristics

Fortunately, some characteristics of the cosmics are specific. The intensity profile is sharper than for a real object. This can be used by algorithms that filter for cosmics, e.g. from IRAF. For an overview on the cosmic filtering possibilities of IRAF, see (Wells, 1994). However, it is difficult to fine-tune the parameters, so that no real objects are lost due to the filtering. This applies especially, if the objects of interest are faint.

3.2. Use of Median Image

For applications that are not interested in detecting moving objects, a median of several images of the same star region can be computed, which eliminates the cosmics. This method can usually not be used for the search of debris objects as moving objects are eliminated as well.

3.3. Use of Predicted Location for the Objects of Interest

If three or more exposures are available for the same star region with an unknown object on each (which might be a real object or some cosmics), the initial position and the apparent velocity of the unknown object can be calculated from the first two images. A linear extrapolation may then be used to predict the positions of the potential object on the remaining frames (see Fig. 6 for an outline of the idea). If the unknown object is not found in the vicinity of these predictions, it can be deduced, that the object probably is not real.

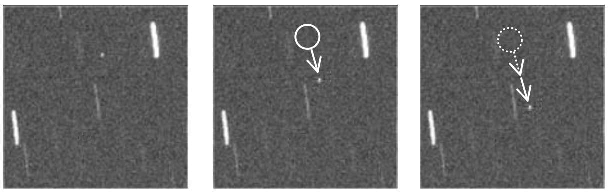

Figure 6. Exposure series of three consecutive images of the same star region (enlarged part of an exposure taken at the ESASDT at the Tenerife Observatory; the moving object is simulated on the images).

If only two images are available, a weaker variant of this method can be used based on some reasonable assumptions concerning the apparent velocity of the objects of interest on the exposures. Pairs of unknown objects from both images can then be checked, whether their distance conforms with the assumed velocity range or not. Unknown objects, for which no partner on the other image is found that conforms to the velocity assumption, are usually cosmics, or other artefacts.

4. FAINT OBJECTS

Faint objects are a special challenge for the image processing algorithms. See Fig. 7 for an example of a faint object.

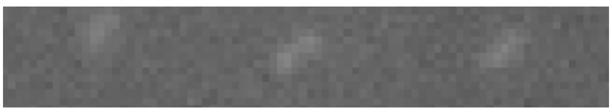

Figure 7. (The same) faint geostationary object on three different frames (exposures taken with the ESASDT at the Tenerife Observatory).

4.1. Point-like Object

In this case, the signal of the faint object is entirely concentrated in one pixel (or only a few of them). If the signal is too weak with respect to the noise of the background, the object cannot be detected.

4.2. Streak-like Object

In this case, the signal of the faint object is spread over many pixels. To detect the object, it might be necessary to use specific algorithms, that accumulate the signal of the whole streak. This may be algorithms that search explicitly for objects of a given length and orientation using spatial filters. Another type of algorithm is the Hough algorithm (Leavers, 1992) that searches for all directions simultaneously. However, these algorithms are computationally expensive. For the Hough algorithm variants exist that need less computing power. However, they are limited to special cases.

As the signal of the object is faint, it might be below the background noise at some pixels. Then the detection process only succeeds for parts of the trace of the debris object, and the resulting trace may appear to be discontinuous. The algorithms then have to recombine these parts.

5. SUMMARY

An overview over the problems that are typical for the processing of CCD exposures of space debris objects (or other objects that move with respect to the stars and might be faint) was given. Different methods that can be used to cope with these problems and their advantages and disadvantages have been summarized.

6. REFERENCES

Leavers, V.F., *Shape detection in computer vision using the Hough transform*, Springer Verlag, 1992.

Schildknecht, T., Hugentobler, U. and Verdun A., Algorithms for ground based optical detection of space debris in GEO and GTO, *First International Workshop on Space Debris*, Moscow, Russia, October 9-11, 1995.

Wells, L.A. and Bell, D.J., *Cleaning Images of Bad Pixels and Cosmic Rays Using IRAF*, September 1994, online documentation, http://iraf.noao.edu/iraf/ftp/iraf/docs/clean.ps.Z.