P01

東京大学木曽観測所モザイク CMOS カメラ「トモエゴゼン」による高速移動天体サーベイ

Survey of Fast Moving Objects with a CMOS Mosaic Camera, Tomo-e Gozen, at Kiso Observatory

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東京大学木曽観測所では 1.05 m シュミット望遠鏡用の旗艦観測装置として高感度 CMOS センサを使用したモザイクカメラ, トモエゴゼン (Tomo-e Gozen) の開発を進めてきた. トモエゴゼンは広視野・高感度・連続読み出しを達成した初の天文用カメラであり，合計 20 平方度の領域を最大 2 Hz でモニタリングできる. 木曽観測所ではトモエゴゼンの動画撮影能力を活かして，高速移動天体サーベイを実施している. 一視野あたり 2 Hz で 9 秒間の動画観測を繰り返すことで, 3 時間程度で約 7,000 平方度の領域を監視できる. 月距離の数倍以内に近づいてきた地球接近小惑星や，静止軌道付近にある人工衛星やスペースデブリの検出にも高い能力を発揮する.これまでに 13 天体の地球接近天体の発見に成功した. 発表ではサーベイの概要と移動天体を抽出する手続きについて解説する.

Tomo-e Gozen is a newly-developed mosaic CMOS camera mounted on the 1.05-m Schmidt Telescope at Kiso Observatory, the University of Tokyo. Equipped with highly sensitive CMOS sensors, Tomo-e Gozen becomes a unique camera for astronomy with a high sensitivity, a wide field-of-view, and a capability of video observation. Tomo-e Gozen is able to monitor a 20 square-degree sky continuously at up to 2 Hz. The video observation with Tomo-e Gozen provides an opportunity for a survey of fast moving objects. About 7,000 square-degree area can be observed in about 3 hours, while a single field is monitored at 2 Hz for 9 seconds. One of main scientific targets is a near-earth asteroids which approach to the Earth within a few lunar distances, while this survey achieves a high performance in detecting artificial satellites and space debris as well. We have discovered 13 new near-earth asteroids as of September 11th, 2020. In the presentation, we'll describe details of the survey and explain the procedure to extract fast moving objects from the video data.

Survey of fast moving objects with a CMOS mosaic camera, Tomo-e Gozen, at Kiso Observatory

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Summary

- A wide-field CMOS mosaic camera Tomo-e Gozen is developed in Kiso Observatory, which has a capability to monitor a sky of about 20 sq-deg. at up to 2 fps.
- We develop a pipeline to efficiently extract fast moving objects from video data obtained in the Tomo-e Gozen's High-Cadence Transient Survey.
- In the first 1.5 years of operation, Tomo-e Gozen has detected 20 new near-earth asteroids, as well as a number of cataloged and uncataloged space debris.

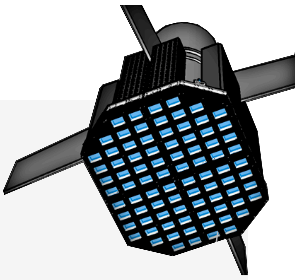

Fig 1. The Tomo-e Gozen camera.

Background

There are a number of space debris orbiting the Earth. It is important to track their motions and to comprehend statistics of the space debris for sustainable space utilization. Currently only a fraction of the space debris, however, is monitored. There has been increasing demand in finding untracked space debris. Untracked space debris is usually observed as moving objects. A typical apparent motion of the debris is larger than 10 arcsec/sec. A practical method to find such fast moving objects in a blind survey is required.

Tomo-e Gozen

Tomo-e Gozen is a newly-developed mosaic CMOS camera (Fig. 1) mounted on the 1.05-m Schmidt Telescope at Kiso Observatory, the University of Tokyo. Equipped with highly sensitive CMOS sensors, Tomo-e Gozen becomes a unique camera for astronomy with a high sensitivity, a wide field-of-view, and a capability of video observation. Tomo-e Gozen is able to monitor a 20 square-degree sky continuously at up to 2 fps.

Tomo-e Gozen daily carries out a transient survey. About 7,000 square-degree area is observed in about 3 hours. In each field, Tomo-e Gozen obtains videos at 2 fps for 9 seconds (Fig. 2). More than 15,0000 video clips are recorded in a clear night. This makes Tomo-e Gozen one of the most powerful facilities to detect fast moving objects in a blind survey.

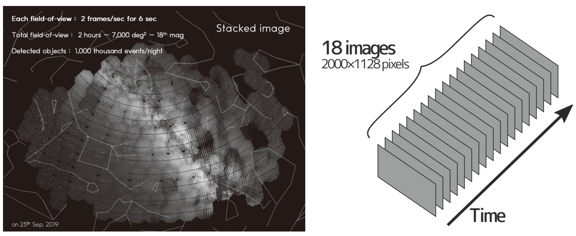

Fig 2. An overview of the Tomo-e Gozen transient survey.

One of main scientific targets is a near-earth asteroids which approach to the Earth within a few lunar distances. On the other hand, this survey achieves a high performance in detecting artificial satellites and space debris as well. To make the best use of this survey, we have developed an automated pipeline to extract fast moving objects from video data.

System Overview

The fast moving object processing system is schematically described in Fig 3. Sources are extracted from the entire video. A mask for fixed sources are created from the first and last frames. Fixed sources are masked out. Moving object candidates are identified by clustering the remaining sources.

We adopted two tricks to facilitate the clustering process. First, a k-nearest neighbor graph is constructed (orange arrows), where each edge is regarded as a proposed motion vector. Then, a line segment clustering algorithm is applied to the edges. The clustered sources are indicated by the green arrows. The pipeline can process the data immediately owing to the tricks.

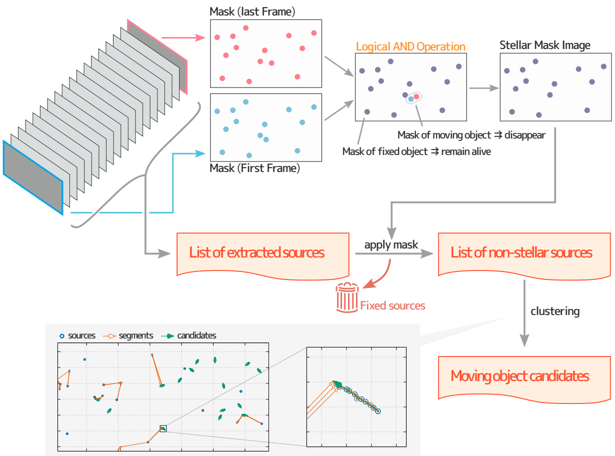

Fig 3. A schematic view of the moving object clustering procedure.

The formal operation has started since October 2019. As of February 2021, 20 near-earth asteroids have been newly discovered (Fig. 4). Tomo-e Gozen has been recognized as one of the leading facilities in the NEA detection. A lot of uncataloged space debris is detected as well. The right panel of Fig. 4 shows the sky distribution of detected objects on October 5, 2020. Objects without counterparts are indicated by the arrows with the orange circles.

Refer to the poster presented by K. Mitsuda et al. for detailed statistics.

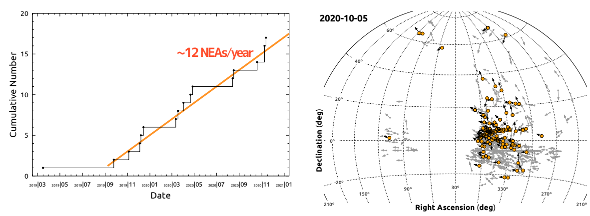

Fig 4. Statistics of the fast moving object processing pipeline outputs.

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