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DEVELOPMENT OF ASTEROID DETECTION APPLICATION "COIAS" FOR THE SUBARU HSC DATA

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Extended Abstract—

1. Background

1-1. Small asteroid population

More than a million asteroids have been discovered since the discovery of Ceres in 1801. In 1918, the concept of "asteroid family" is suggested from the orbital distribution of known 940 asteroids at that time (Hirayama 1918). The asteroid family is a population of asteroids that share similar orbital elements. The members of families are thought to be collisional fragments that were produced by the impact event on the parent asteroid. The orbital distribution of asteroid families broadens in time due to the variation of escape velocity for ejected fragments, and the Yarkovsky effect (Vokrouhlický et al. 2006). The Yarkovsky effect changes the semi-major axis of asteroids due to the anisotropic emission of thermal photon. The effect is particularly prominent for asteroids with diameters smaller than 300 m. A mechanism of orbital evolution from main-belt asteroids (MBAs) to near-Earth objects (NEOs) is thought to be the injection of collisional fragments to the orbital resonance. The information of orbital distribution for asteroids with diameters smaller than 300 m has importance to make clarify the broaden mechanism of asteroid families and the orbital evolution from MBAs to NEOs. However, most of the discovered asteroids in the main-belt region have diameters larger than 1 km. The orbital distributions of asteroids cover the range of 300 m in diameter have not been clarified.

1-2. Subaru HSC

Hyper Suprime-Cam (HSC) is a super wide field camera mounted with the prime focus of 8.2 m Subaru telescope. The field of view covers the area of 1.5 deg in diameter by 104 CCD chips. A part of observations using HSC are conducted based on the Subaru Strategic Program (SSP). The survey strategy of the SSP is mainly designed for the scientific aims of gravity lens, galaxy formation, supernovae, and the Milky Way. The survey started in 2014 and covered around the area of 1400 deg^2. In the solar system science, HSC was used for the clarification of the asteroid size distribution, the color investigation of TNOs and Centaurs, the search of the Planet Nine, etc., by the Open Use Proposal without the SSP. All the HSC data are archived and opened a year and a half later from the observations. A large number of asteroids with diameters smaller than 300 m will be imaged in such an archived data. The data accumulation by the discovery report to the Minor Planet Center (MPC) is important for the solar system science. As described above, 300 m-sized asteroids are not discovered enough in the main-belt region. The clarification of orbital distribution for such asteroids has enough scientific meanings. However, the coordination and brightness of these asteroids were not reported effectively to the MPC. The reason is thought to be that there was no useful application system which can conduct the detection, measuring coordinates, photometry, and reporting to the MPC for asteroid. Developments of the smooth detection and report system are required for asteroids that are imaged by the Subaru HSC.

1-3. Citizen Astronomy

GALAXY CRUISE is a Citizen Astronomy project (citizen science in astronomy) run by the National astronomical observatory of Japan (NAOJ). This project carries out galaxy morphological classification by using the HSC collaborating with citizens. Moreover, this project is designed to make it easy for citizens to conduct data analysis by allowing them to visually handle the HSC images from their own computers via the internet. Developments of an application system based on the concept of GALAXY CRUISE will give an experience of asteroid discovery as the education to citizens and students.

2. COIAS

In order to solve the background problems, we started to develop “COIAS (Come On! Impacting ASteroid)” which is an application system for detecting, measuring coordinates, photometry, and reporting to the MPC about asteroids imaged in the HSC. The name COIAS comes from a Japanese animation, K(C)oisuru Asteroid (its abbreviated name is K(C)oias), the English title is “Asteroid in Love”. This animation is a story of high school students who try to discover asteroids. We adopted this animation title for our application name considering the educational and public relations effect.

COIAS is composed of our developed programs and the relevant system. One of the problems for detecting moving objects distinguishes between noise and asteroids. COIAS removes the false detection in visual way using the Graphical User Interface (GUI). The GUI is shown in Figure 1. The detection of moving objects by machine learning algorithm was considered for the Subaru HSC (Lin et al. 2018). However, the HSC data were obtained under a variety of conditions, such as exposure time, filter, and survey area. The machine learning algorithms are difficult to be applied for the variety of conditions. Thus, we decided that the visual inspection is better than machine learning algorithms in the current situation. In addition, the visual inspection gives citizens and students the delight of asteroid discovery and is expected to have a high educational effect.

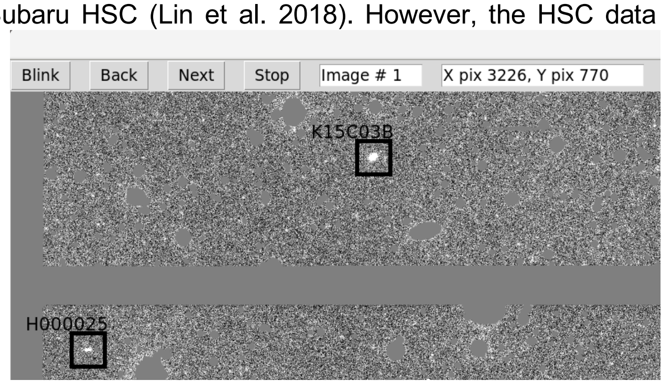


Figure1. A part of the COIAS GUI. H00025 is an unknow object. K15C03B is a known object.

The flowchart of COIAS is summarized in Figure 2. Asteroids detection requires more than multiple images which were obtained in the same region at appropriate time intervals. In our case, we used five images. First, images suitable for asteroid detection are selected from the HSC archive data. Next, bias correction, flat field correction, and star removal are performed using the HSC pipeline developed in collaboration with NAOJ, Princeton University, and the University of Tokyo. The moving objects are detected by the following standard procedures.

1. Source detection in the first image at the time of t1. The coordinate is expressed as $[x_1(t_1),y_1(t_1)]$.
2. Calculation of moving velocity between the first image and the second image. The moving velocity is written in $\Delta x = (x_2(t_2)-x_1(t_1))/(t_2-t_1)$, $\Delta y = (y_2(t_2) - y_1(t_1))/(t_2-t_1)$.
3. The estimated coordinate in the third image is described $x_3 = x_2 + \Delta x(t_3-t_2)$, $y_3 = y_2 + \Delta y(t_3-t_2)$
4. Search for a point source within 3.6 arcsec around the estimated coordinates.
5. The same procedure is applied for the fourth image and fifth image. The candidate of moving object is defined as the source that is detected more than four times.

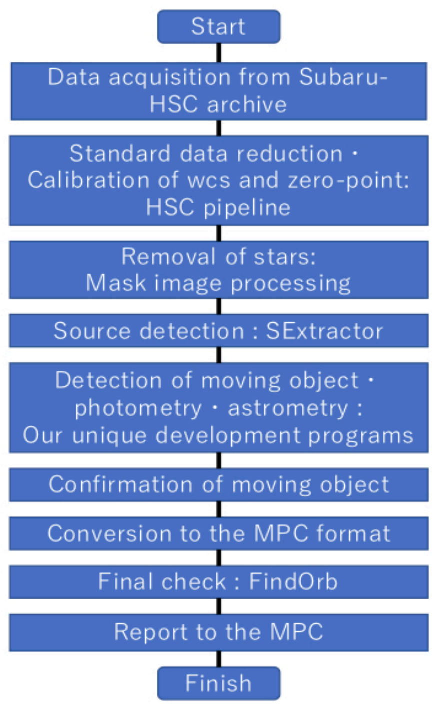
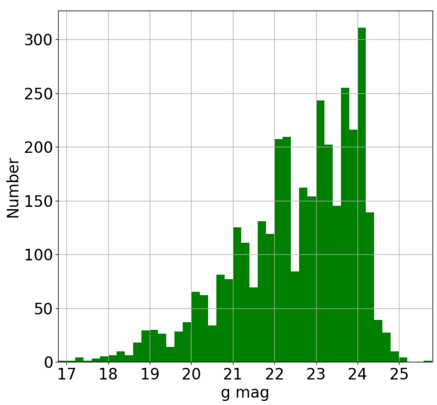


Figure 2. The flowchart of COIAS.

After the detection of moving objects, we check the candidates by the visual inspection with a so-called "Blink" method. Finally, the coordinate and photometric measurement results are converted to the MPC format and reported to the MPC.

3. Asteroids detection test

We have performed an asteroid detection test using COIAS. The test data were obtained when a main author observed Jupiter Trojans on 26 January, 2015. The observation areas are located around opposition on the ecliptic plane. The exposure time is 240 sec for the *g* and *r* filters. We detected 4141 unknown objects and 874 known objects from the area of 16 deg^2. Then, the results were reported to the MPC. About 90 % of objects are main-belt asteroid candidates, 7-8% of objects are Hungaria group candidates, and 2-3% of objects are NEO candidates. Figure 3 shows the magnitude distribution. Although the trail loss effect arose for main belt asteroids because the main target of this observation is Jupiter Trojans, asteroids up to about 24.2 mag have been detected validly. Assuming the albedo of 0.1 and the semi-major axis of 2.5 au, the brightness of 24.2 mag roughly corresponds to 200 m in diameter. Subaru HSC can reliably detect asteroids smaller than 300 m in diameter.



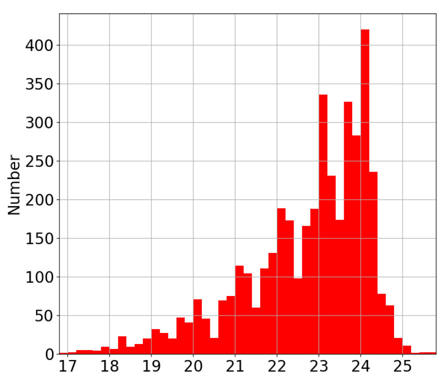


Figure 3. Magnitude distributions in the *g* band (Top) and the *r* band (Bottom).

4. Summary and future work

We started to develop the asteroid detection application COIAS for Subaru HSC data. COIAS can perform detection, measurement of coordinates, photometry, and reporting to the MPC more smoothly than ever before. However, COIAS is in an early phase of development. The processes using the HSC-pipeline requires around one day. The detection of moving object takes about 15 minutes per 10 % of the field of view (= 0.17deg^2). The visual inspection requires around 15 minutes for the same area. In addition, handling COIAS requires knowledge and skills of a college student level because some processes run by command line interface. We cannot say that the usability of the present GUI is user-friendly. We think that COIAS needs significant improvement to be adapted for the citizen astronomy at present. On the other hand, we launch a new effort to improve the usability of COIAS by collaborating with the private corporation. In parallel, we will continue to improve the programs and increase the efficiency of the automatic asteroid detection part. HSC archive data will continue to increase in the future. COIAS will contribute to the discovery of asteroids, including NEOs.

References

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