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Analysis of Monitoring the Near-Earth Asteroids

Yongshi Zeng

College of Physics and Information Engineering, Guangdong University of Education, Guangzhou, 510303, China
Corresponding author: leimeimiao@ldy.edu.rs

Abstract:
Over a thousand individuals were hurt when a celestial body fell near Chelyabinsk, Russia, in 2013. Asteroids will inevitably strike Earth, causing unimaginable harm, according to historical experience and evidence from astronomical observations. One of the main purposes of monitoring and warning of asteroids is to protect the Earth from the harm of asteroid impacts. There is very little information available on Asteroids monitoring, despite its significance. Planetary exploration and discovery are receiving far more attention than the limited amount of study on monitoring near-Earth planets. Several space-based optical monitoring investigations were included in this small body of monitoring research. This paper talks about the perspectives of ground-based and space-based instruments, optical observations, and radar micro-observations, the working principles, advantages, and disadvantages of different monitoring instruments are compared, and the development prospects and significance of this research are explained. The study found that the current instruments are of a single type and have many limitations in monitoring the orbits of near-Earth asteroids. Therefore, this article believes that it is meaningful to develop coordinated observations between the sky and the earth, combining the advantages of different types of monitoring instruments and improving the monitoring system of near-Earth asteroids to protect the Earth from the harm of asteroid impacts.

Keywords: Near-Earth Asteroids, monitoring, Ground-Based, Space-Based

1. Introduction

With the advancement of science and technology, research in astrophysics has become increasingly in-depth, and how to protect the Earth's stable existence in the universe has become an issue worthy of study. Asteroids are celestial bodies in the solar system that orbit the sun similar to planets but are much smaller in size and mass than planets. Some near-Earth asteroids have orbits that intersect with the Earth. They move near the Earth, so they are called "near-Earth asteroids." Asteroid collisions with Earth are a possibility due to the proximity of near-Earth asteroids, such as the Apollo and Aten types, whose orbits in-

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tersect with Earth's orbit. Due to their orbital characteristics, these near-Earth asteroids may have an impact on the safety of the Earth. Therefore, it is very important to monitor and study them to better prevent them from colliding with the Earth.

The monitoring and early warning of near-earth asteroid impact is a popular research direction of astrophysics at present because monitoring the activities of near-earth asteroids can timely warn the orbit of asteroids, and establish defense plans in advance to achieve the purpose of defense. There is still a dearth of information about Near-Earth Asteroids, despite their significance. While considerably more study is being done on planetary exploration and discovery, there is a tiny amount of research on monitoring near-Earth planets. A handful of these monitoring investigations referred to space-based optical monitoring. As a result, this problem has not gotten much attention in the academic literature up to this point.

Using already-existing ground-based equipment, some studies have employed image processing and orbit determination techniques to accomplish coordinated monitoring and orbit cataloging of near-Earth asteroids, as well as target detection and astronomical positioning in ground-based observation images and precise orbit determination [1].

In terms of monitoring and early warning of near-Earth asteroids, researchers have studied theoretical contents such as the Lagrange L1 and L2 points [2] and the Venus-like orbit. The Earth's orbit contains the Venus-like orbit, and the Earth's orbit direction is monitored simply along the path of sunlight, creating a favorable monitoring geometry. Therefore, the Venus-like orbit can better monitor the dangerous near-Earth asteroids surrounding the Earth from the direction of the sun[1]. Space powers represented by the United States and Europe have long launched near-Earth asteroid observation and defense plans. For example, the NASA Near-Earth Object Observation Program was established in 1998 after the agency started doing scientific research and holding seminars on near-Earth object identification, characterisation, and tracking in 1992[3]. Although the current asteroid exploration work has achieved fruitful results, there are still many dangerous asteroids that have not been observed.

This article will analyze the use of a combination of multiple strategies to adopt relevant and effective monitoring plans for potentially threatening asteroids. First, four different types of monitoring instruments are listed, and then the working principle of each monitoring instrument is analyzed. The advantages and disadvantages of the four monitoring instruments are compared, and methods for further developing monitoring technology are summarized to buy more time for the formulation of near-Earth asteroid impact defense strategies and deployments. It is hoped that this study will help mankind gain a deeper understanding of the nature of asteroids. By analyzing the combination of ground-based and air-based observation methods and supplementing optical and microwave observations, people will actively promote the establishment of a framework for sharing asteroid observation data around the world and further promote the rapid development of monitoring and early warning work.

2. Observation and Monitoring Technology

2.1 Monitoring System Classification

A graphic representation of the variety of methods now employed to track asteroids and give alerts may be found in Figure 1. These techniques fall into one of two categories: ground-based or space-based, depending on the location of the observation site. Technical concepts allow for additional division of ground- and space-based detection technologies, such as optical and radio detection.

2.2 Ground-based Observation and Space-based Observation

Ground-based observations refer to observations based on ground-based sensors. Space-based observations refer to observations with sensors located outside the Earth's atmosphere. Through the selection of satellite orbits, global data with high spatial and temporal resolution can be obtained.

At the moment, the primary technique for tracking asteroids is optical observation. It uses sunlight reflected off an asteroid's surface to calculate an asteroid's location by repeatedly taking pictures of the same sky at various times. Although ground-based optical observation equipment is mostly found in the northern hemisphere, it is very dependent on favorable observing circumstances, is readily interfered with, and has a large operational range at cheap construction and running costs. There are some geometric discrepancies in the observation data since there is less observation data in the southern hemisphere.

Space-based observation has the benefit of covering the entire planet and not being impacted by atmospheric and ionosphere-related phenomena as compared to ground-based observation. The space-based telescope in the space-based optical measuring model is situated in the earth's orbit; in contrast to the ground-based observation station, its position is not locked to the planet [4]. Since it can be flexibly distributed in LEO orbit, Earth-Sun Lagrange point, Venus orbit, and other locations, it can over-come most interference factors, make up for the blind spot problem of ground-based monitoring systems in the area of sunlight, and greatly improve detection efficiency. In addition, space-based observations are less affected by the atmosphere, so they are more suitable for monitoring and early warning.

High detection sensitivity and wide detection range are only two of the numerous benefits of infrared astronomical observing equipment. In addition to aggressively planning the next generation of tiny celestial body space observation telescopes, the United States launched the Near Earth Object Wide Field Infrared Survey Satellite (NEOWISE) in 2009 [5]. Identifying the materials on the planet's surface and estimating characteristics like temperature and albedo are only a few of the many uses for infrared monitoring, a unique optical observation approach with a reduced skylight backdrop, and several benefits for spectrum analysis and daylight observation.

Radio waves are electromagnetic waves with wave properties, and their wavelengths are usually between 1 mm and 1 cm. Specialized equipment is required to see radio waves since their wavelength is so long that the human eye can't see them directly.

Radio waves are not readily impacted by weather or air pollution, unlike visible light, and they may pass through clouds, haze, and other materials.

3. Existing Monitoring Equipment

3.1 Ground-based Observation

3.1.1 Catalina sky survey

The Catalina Sky Survey (CSS) is another famous near-Earth asteroid monitoring project in the United States after the LINEAR program. It is a typical ground-based sky survey system. This system's primary purpose is to investigate and find comets, asteroids, and near-Earth asteroids—especially those with a diameter larger than 140 meters. Over 90% of near-Earth objects with a diameter larger than 140 meters may now be cataloged thanks to authorization from the US Congress granted to the CSS team [5].

It consists of the 1.5-m survey telescope, the 1.0-m follow-up telescope, and the 0.7-m survey telescope, and all three sites use the same thermoelectric cryogenic imaging sensors and software systems. The 1.5-m survey telescope is an f/1.6 reflector equipped with a 111-megapixel (10,560 x 10,560 pixel) CCD detector mounted at prime focus. Covering 1000 square degrees per night with a limiting magnitude V~21.5 images are obtained using a 2 x 2 binning mode with an exposure time of 30s. The 1.0-m follow-up telescope typically recovers 40-80 targeted NEOs per night with a limiting magnitude V~ 22.0. The 0.7-m survey telescope is an f/1.8 Schmidt catadioptric [6]. Its robust observation capabilities and coverage of the northern and southern hemispheres' astronomical observation locations fill in the gaps left by earlier asteroid observation networks.

3.1.2 Five-hundred-meter aperture spherical radio telescope

An elementary tool for monitoring and analyzing radio waves from celestial bodies is a radio telescope. Asteroids further than 0.3 AU from the sun cannot be seen by radar due to its low viewing range. This makes radio observations challenging to perform if the asteroid's location is unknown, which further complicates the use of this technology for asteroid monitoring. Star activity with exceptionally high electromagnetic signal characteristics is typically seen using radio telescopes [5]. Five-hundred-meter Aperture Spherical Radio Telescope (FAST) in Guizhou, my country is the world's largest single-aperture radio telescope with extremely high sensitivity. In the pit is an active reflector in the shape of a spherical crown that has a 500 m diameter. The instrument is designed to gather radio waves released by astronomical bodies and is comprised of thousands of reflector components. The high-precision feed placement required by the telescope is satisfied by constructing a flexible cable drive mechanism and implementing a parallel robot system in the feed cabin[7]. FAST requires very low levels of electromagnetic interference at the location to monitor faint electromagnetic signals from far-off celestial bodies in the cosmos. Sustaining a favorable radio wave environment is a crucial prerequisite for the scientific output of FAST. With a multi-band, multi-beam feed and receiver system that spans frequencies from 70 MHz to 3 GHz, FAST can research a wide range of subjects, such as pulsars, interstellar molecules, and potential interstellar communication signals [8].

3.2 Space-based Observation

3.2.1 Wide-field infrared survey explorer

The Wide-field Infrared Survey Explorer (WISE) can fill the gap in mid-infrared band images in all-sky surveys and is currently one of the major asteroid space-based observation systems in the world. Given the wide-field infrared survey Explorer satellite's exceptional sensitivity and five standard deviation limits at 120, 160, 650, and 2600 microns as well as 3.3, 4.7, 12, and 23 microns, NASA officials thought in 2007 that the satellite could be used in the near-Earth object survey mission to detect objects with

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internal energy heat. The SDL laboratory in the United States has completed the development of the all-aluminum optical system for the Wide Field Infrared Survey Explorer (WISE, launched in 2009) infrared astronomical satellite. The 10 mirrors and 3 flat mirrors in WISE are all made of aluminum alloy material RSA-6061, which can operate in ultra-low temperature environments of 10 K (-263℃) [9]. By continually scanning a region of the sky and supplying a sequence of images for computers to analyze, WISE can spot objects that move against a fixed backdrop of stars, such as near-Earth asteroids. Asteroids generate less heat when they are near the sun, which makes them more ideal for infrared research than visible-light telescopes.

3.2.2 Near-earth object surveyor space telescope

Near Earth Object Surveyor (NEO) proposed by the United States is scheduled to be launched to the L1 point on Earth in 2028, to catalog over two-thirds of the 140-meter diameter near-Earth asteroids within 5 years [10]. Its goal is to support NASA's planetary defense mission by assisting in the identification and characterization of the majority of potentially dangerous asteroids and comets that are within 30 million miles of Earth's orbit. NEO is a space-based infrared telescope. Space-based observation platforms have a significant advantage in terms of target feature acquisition and observation coverage due to their ability to eliminate the atmosphere's influence to the greatest extent possible and their lack of reliance on fixed observation sites. Additionally, these platforms allow for extended periods of continuous observation. In addition to precisely measuring near-Earth objects' sizes, it also gathers important details about their composition, shape, orbit, and rotation state by utilizing two thermally sensitive infrared imaging channels. It observes asteroids using infrared radiation. Infrared astronomical observation offers absolute benefits over visible light observation technology, which is now more widely utilized. These advantages include a better capacity to view dark and weak celestial bodies in space and the ability to get richer spectral information about asteroids. Thus, for space-based observation systems, telescopes operating in the infrared range are the favored choice [5]. Asfaltes with highly hot surfaces will be easily recorded by infrared telescopes operating at these wavelengths, as they will be sensitive to heated objects. Launching the device using a sunshield into a halo orbit at the Sun-Earth Lagrange point 1 is scheduled for 2025. The mission is expected to run for twelve years. To find at least two-thirds of NEOs larger than 140 meters in diameter—large enough to inflict substantial regional damage if they impacted Earth—the device will perform a five-year baseline scan.

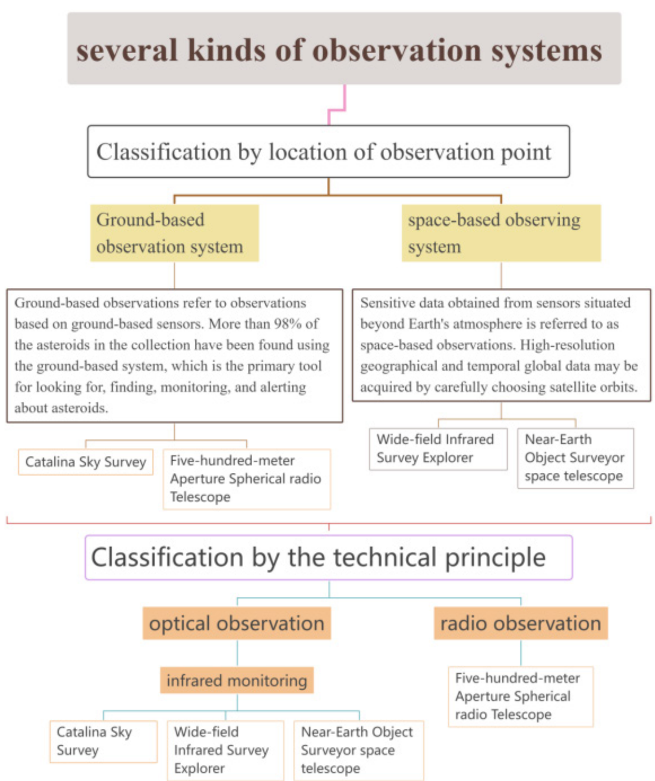

Fig. 1 Classification of observation instruments at different angles (Photo/Picture credit: Original).

3.3 Analysis and Comparison

Early on, and now comparatively mature, was the ground-based monitoring and early warning system because using ground-based observation tools, the first known asteroid was found in 1801, and since then, these tools have been developed further. Although it began gradually, the in-orbit mission of the space-based monitoring and early warning system is already in place. The development of the space-based early warning and observation system is moving somewhat slowly because of problems with danger, cost, and maintenance.

As shown in Table 1, it is impossible to provide entire airspace, all-day monitoring, and early warning because of the intrinsic flaws in the ground-based monitoring system, which are primarily sensitive to sunlight and unequal distribution in the north and south of the planet. Space-based observation and early warning systems are combining to complement one another and learn from each other's advantages and disadvantages. This is the current development trend. The limitations of ground-based observation equipment are its small number, single station location, tiny caliber, and restricted detecting capabilities. It can only currently monitor objects that are closer to Earth than magnitude 20, and it can only warn of impending collisions for a limited number of objects. There are not many space-based observation programs and they are still in the demonstration phase. For thorough monitoring, an efficient observation network is generally lacking, and systematic sample forecasting and early warning are unachievable.

The following main scientific issues are inevitable (but are not limited to): (1) Precise orbit prediction of asteroids; (2) Rapid orbit determination and high-precision orbit improvement; (3) Dynamical model of asteroid orbit evolution, etc [11]. NASA and the European Space Agency have proposed relatively clear mission objectives for the asteroid monitoring project. NASA has set a 2030 deadline for verifying the presence of at least 90% of celestial bodies larger than 140 m in diameter. In the meanwhile, ESA feels that near-Earth asteroids less than 1 km should be detectable by upcoming observation telescopes.

Table 1. Comparison of two kinds of observation systems

parameter	Observation platform	
	Ground-based observation system	Space-based observation system
Observation band	Optical observation	
	Radio observation	
Observation object	Near Earth and Deep Space	Deep space exploration has more advantages
Observation distance	Affected by atmospheric disturbance, the observation distance is limited	Get rid of atmospheric interference and have longer detection range
Observation error	Affected by atmospheric disturbance, The error is large	Get rid of atmospheric interference and have small error
Technology maturity	The technology is relatively mature	Initial stage and Large room for development
Benefits	Early on, and now comparatively mature, was the ground-based monitoring and early warning system and the cost is low, and there is no need to consider the difficulty of on-orbit maintenance and the greater impact of cosmic radiation.	Although it began gradually, the in-orbit mission of the space-based monitoring and early warning system is already in place
Drawbacks	Largely exposed to solar radiation, they are sporadically found in both the north and south of the planet, have tiny populations, isolated single-station sites, narrow apertures, and poor detection powers. Only objects closer to Earth and with a magnitude greater than 20 can be monitored	It's in the demonstration phase right now. Comprehensive monitoring cannot be accomplished using sample prediction or early warning systems. Ineffective surveillance networks may come with expenses, hazards, and maintenance problems
Possible development	Based on the investigation's findings, various combinations of schemes, such as ground-based and space-based, optical and radio monitoring, and more, can be employed to create monitoring systems for near-Earth asteroids. Networked collaborative observations are carried out at various orbits and locations by ground-based and space-based telescopes.	

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4. Conclusion

This paper presents a novel comparison of the operational principles and benefits and drawbacks of space-based and ground-based monitoring instruments. The comparative analysis results obtained from this comparison provide support for the assessment of the near-Earth asteroid monitoring system's overall effectiveness and design. The results of this investigation show that to design ground-based and space-based monitoring systems for near-Earth asteroids, several scheme combinations may be used, including ground-based and space-based, optical and radio monitoring, and more. This thesis has provided a deeper insight into the development of near-Earth asteroid monitoring systems. According to the study's comparative research, a coordinated system of radio radar and optical ground-space observation techniques can enhance the system for monitoring near-Earth asteroids and provide fresh perspectives on the all-encompassing advancement of planetary monitoring.

The search, discovery, location, orbit determination, cataloging, and impact probability calculation of target asteroids with impact risks, as well as the support of in-orbit disposal, disaster relief, and international cooperation, are the first steps toward effectively managing the impact risk posed by near-Earth asteroids.

To improve the monitoring system structure and produce a more complete and technically possible plan, as well as to anticipate and efficiently address the impact dangers posed by near-Earth asteroids, further research, and comparative demonstration are necessary in the future.

Unfortunately, this study did not include all types of ground-based and space-based telescopes to conduct a comprehensive comparative analysis. Although this study is exploratory, it provides some insights. More data on the combination of various monitoring techniques should be investigated in subsequent research to support the establishment of greater accuracy in the creation of monitoring systems.

Based on both historical records and data from astronomical observations, it is certain that asteroids will collide with Earth, causing immense harm. Preparing for potential emergencies and safeguarding Earth against asteroid strikes are two of the primary goals of monitoring near-Earth asteroids.

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