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WHAT IS THE EFFICIENCY OF CURRENT AEROSPACE TECHNOLOGIES IN DETECTION AND DEFLECTION OF POTENTIALLY HAZARDOUS ASTEROIDS?

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ABSTRACT

The growing realisation of the potential for an asteroid impact has led to a focus on whether current aerospace technologies are sufficient when it comes to detecting PHAs and attempting to deflect them. This paper explores the extent to which current space-based and ground-based telescopes, as well as the deflection strategies, are adequate means for defending against asteroids. A comprehensive review of detection capabilities highlights both the strengths and limitations of current detection and deflection techniques. Substantial progress has been made to advance this knowledge, particularly with missions such as NASA's DART, but current technology is inadequate ensuring that every asteroid threat can be addressed reliably and in a warning time frame. The paper concludes by identifying critical areas for enhanced deflection methods, to ensure a more robust planetary defence system in the future.

KEYWORDS: PHAs, Asteroids, Deflection, Velocity, Spacecraft, DART, Gravity Tractor, NED

INTRODUCTION

The inevitable threat of asteroids and near-Earth objects (NEOs) hitting our planet has long been a matter of public concern and scientific research. According to the Lunar and Planetary Laboratory at the University of Arizona, Earth has suffered up to 3 million impact craters larger than one kilometre in diameter (Science Time, 2021). Recent advancements in aerospace technologies have increased the ability to detect and mitigate NEOs approaching our planet. Without any warning in February 2013, a meteor came towards a city in Russia and exploded in the sky, releasing shockwaves that had 20–30 times more energy than a WWII atomic bomb (Johns Hopkins Applied Physics Laboratory, 2019). Such instances led to the conclusion that our planet requires advanced detection and deflection technologies to avoid devastating collisions that may pose a significant threat to humanity. As we gain a deeper understanding of the NEOs surrounding us, so does our scope of analysing, detecting, deflecting, and protecting mankind from a potentially hazardous collision.

Current modernised technologies "somewhat effectively" assist in asteroid detection and deflection. The ground-based telescopes and space-based observatories have significantly improved our capacity to monitor and track any NEO activity. Moreover, the kinetic impactor and nuclear explosive device have played a pivotal role in diverting the trajectories of such asteroids, providing a strengthened defence strategy. Several missions, such as the DART from NASA, have successfully been implemented, promising bright prospects for the future of aerospace technologies.

While promising, these mechanisms have not promised reliability. Over the years, it has been observed and established that these detection strategies only go so far due to observational limitations and varying sizes and compositions of asteroids. Moreover, deflection techniques are also constrained due to limited intervention time and uncertainties in practical application. The current aerospace technologies offer a level of readiness for detecting and deflecting potentially hazardous asteroids, but ongoing research and development are crucial to strengthening our defences against these threats.

LITERATURE REVIEW

"Detecting and Deflecting the Asteroid Threat" by Excell (2023) from *The Engineer* is crucial for the research topic as it provides an up-to-date overview of technological advancements, such as space missions and ground-based systems, designed to detect and track near-Earth objects (NEOs). Moreover, it highlights emerging deflection strategies, such as kinetic impactors and gravity tractors, providing valuable insights into the real-world capabilities and limitations of these technologies. The article serves as a vital resource for understanding the current state of readiness and the gaps that must be addressed to ensure effective asteroid threat mitigation.

"The Hunt for Hazardous Asteroids: Challenges and Advancements in Planetary Defense" (2024) from *New Space Economy* is vital for the research as it offers a contemporary perspective on the latest advancements and challenges in planetary defence, focusing on space missions, international collaborations, and detection systems. This source helps contextualise the current strengths and weaknesses of aerospace technologies, providing a balanced view of where planetary defence stands and where further improvements are needed, which is the major aim of the research, to analyse the current technologies.

"Defending Earth: Strategies for Deflecting Hazardous

Asteroids" (2024) from *New Space Economy* delves into the specific methods being developed to prevent asteroid impacts, such as kinetic impactors, nuclear deflection, and other innovative approaches. By examining these strategies, the article provides a detailed look at both the practical application and limitations of present-day technologies. This helps assess whether the current arsenal of aerospace tools is sufficient for successfully addressing the asteroid threat or if further technological advances are required.

The chapter "*Sentinel: A Space Telescope Program to Create a 100-Year Asteroid Impact Warning*" by Reitsema and Lu (2015) is crucial for the research as it focuses on the Sentinel space telescope project, designed specifically to identify potentially hazardous asteroids well in advance. It discusses how Sentinel would contribute to long-term planetary defence by creating a comprehensive catalogue of near-Earth objects (NEOs) and providing early warnings of impact threats. This long-term detection capability is essential for evaluating how well current and proposed space-based technologies can meet the challenge of providing adequate lead time for effective deflection or mitigation efforts. The source offers detailed technical background on one of the most significant detection initiatives, which significantly contributes to asteroid detection.

The video "*Rusty Schweickart: What is the Gravity Tractor Deflection Method for Deflecting NEAs*" (2022) by TheIHMC on YouTube is an informative supporting source for research on the effectiveness of current aerospace technologies for asteroid deflection. In this video, Rusty Schweickart, a well-known astronaut and planetary defence advocate, explains the gravity tractor method, a theoretical technique that involves using a spacecraft's gravitational pull to gradually alter an asteroid's trajectory. This primary source of information helps in understanding the potential of the gravity tractor method as a complementary or alternative solution to current deflection strategies, contributing to the broader discussion of how sufficient today's technologies are in mitigating asteroid threats. This particular source was chosen since Rusty Schweickart co-founded the B612 Foundation, a non-profit foundation aiming to develop technologies and tools to protect our planet from asteroids, thereby making the information more credible for the research.

The video "*DART: The First Planetary Defense Mission*" (2019) by Johns Hopkins Applied Physics Laboratory on YouTube is a vital source for research as it provides an overview of NASA's Double Asteroid Redirection Test (DART), the first mission designed to test the kinetic impactor technique, a direct deflection method involving the collision of a spacecraft with an asteroid to change its trajectory. The video offers insights into the mission's objectives, technology, and expected outcomes, making it a critical example of real-world testing of deflection strategies. This source was chosen particularly since Nancy Chabot, the presenter, is the project scientist in charge of this mission, making her reliable and credible.

"The Role of Artificial Intelligence and Machine Learning in Asteroid Detection" (n.d.-b) from Drishti IAS is highly relevant and important for the research. It highlights the growing integration of machine learning (ML) and artificial intelligence (AI) into asteroid detection efforts. The source demonstrates how effective projects like DeepAsteroid and the THOR (Tracklet-less Heliocentric Orbit Recovery) algorithm help find asteroids that were previously undiscovered. This is in direct line with the paper's goal of overcoming the obstacles that now stand in the way of detection, especially those that have to do with difficult observations and condensed detection windows. The source expands on the research's future-focused topic by examining the potential role that AI and ML may play in the development of asteroid detection technologies.

Current Detection Methods

Currently, we have several promising asteroid detection instruments that comprise mainly ground-based optical telescopes. This primarily includes Hawaii's PanSTARRS (Panoramic Survey Telescope and Rapid Response System) telescope and the NASA-funded Catalina Sky Survey (CSS). Interestingly, it has been established that these facilities are responsible for almost 90% of discoveries and identify around 1,800 objects annually (Excell, 2023). These telescopes capture the extraterrestrial objects hovering in the night sky using wide-field cameras, followed by analysing and observing any potential asteroids or NEOs.

The space-based telescopes provide better observations given that they do not have the disadvantage of atmospheric disturbances. "One of the greatest things it does for us is allow a more accurate estimation of size," said Lindley Johnson, who is head of planetary protection at NASA (Excell, 2023). The NEOWISE mission, which uses NASA's Wide-field Infrared Survey Explorer (WISE) spacecraft, has surpassed its expected lifetime and effectively helped NASA in asteroid detection.

The B612, a non-profit organisation, launched a space-based observatory called Sentinel that aims to detect more near-Earth asteroids than the already present space-based and ground-based telescopes. The Sentinel mission will place an infrared telescope in an orbit around the Sun's interior to the Earth's orbit for about 6.5 years. Sentinel is designed to be conducive to accurate data collection and provide the asteroid's trajectory for the next 100 years (Reitsema & Lu, 2015). This facility allows humans to easily check for the possibility of a collision, plan, and deflect the asteroid off its course within the time of impact.

Moreover, scientists have used radar observations such as the Green Bank Telescope, ngRADAR, NASA's Goldstone Deep Space Communications Complex, RT-70, and several more to estimate the shape, size, orbit, and more accurately detailed information about an asteroid's velocity and distance to plan ahead of time if it clashes with Earth's orbit anytime in the future.

Lastly, the world is evolving to experience more technological advancements, including artificial intelligence and machine learning. Such advancements are also increasingly being used in asteroid detection to create a more accurate understanding of them and their trajectories. To list down a few successful projects, the Asteroid Institute together with Google cloud computing identified 104 asteroids using a new algorithm called THOR (Tracklet-less Heliocentric Orbit Recovery), DeepAsteroid, a software model using the machine learning platform Tensorflow (Google's open-source deep learning platform) that was in NASA's top 25 space apps challenge awards, and NASA asteroid data hunter allows people across the world to upload images from their telescopes and load them for detection. (*The Role of Artificial Intelligence and Machine Learning in Asteroid Detection,* n.d.)

Current Deflection Methods

The most successful and accepted deflection method that has been effectively tested by NASA is the Double Asteroid Redirection Test (DART) mission launched in November 2021. This was humanity's first attempt to test the Kinetic Impactor method. In lay terms, the kinetic impactor would be described as a space rocket simply crashing into an asteroid bound for Earth, which causes the asteroid to deflect and slightly change its trajectory. A tiny impact can also work wonders by changing the trajectory by miles. The DART mission was targeted towards the asteroid Dimorphos and collided with it at a velocity of 6 meters per second, which caused Dimorphos's trajectory to shorten by 32 minutes. This consequently pulled Earth out of threat. The project scientist, Nancy Chabot, stated that the spacecraft is going be destroyed and is not going to be able to measure how much of a deflection it made when this happens; instead, we are going to be using existing telescopes here on Earth in order to make that crucial measurement (Johns Hopkins Applied Physics Laboratory, 2019). This shows how carefully and strategically the technologies of detection and deflection are being interconnectedly used to make the project cost-effective and to obtain accurate details.

Along with the Kinetic Impactor method, the Nuclear Explosive Device is an option for short-notice asteroid warnings. When detonated at an accurately calculated distance from the asteroid, the x-ray radiation from the nuclear explosive device can potentially cause material vaporisation on the asteroid, providing the asteroid with a rocket-like thrust and changing its trajectory (*Defending Earth: Strategies for Deflecting Hazardous Asteroids, 2024*). However, there has not yet been any real test carried out, as this method would result in numerous legal, financial, and environmental consequences for the people already on Earth.

The Gravity Tractor method is another precise and controlled technology in the run for asteroid deflection. The Gravity Tractor method has a unique methodology. A small spacecraft would hover over the asteroid and move along with it using ion propulsion or its own engines; this would eventually exert a 'towing force' upon the asteroid, which would be the weight of the spacecraft. This would cause a slight pull of the asteroid towards the spacecraft, forcing it to change its course, which could take weeks, months, or even a year (TheIHMC, 2022). This method would work wonders as the spacecraft never really has to touch the asteroid, eliminating the risk of breaking down the asteroid into smaller fragments.

Limitations and Challenges

Despite such advancements, the vast and endless nature of space and the celestial bodies surrounding Earth pose unforeseen and unanticipated threats. There are several unresolved limitations that make the detection and deflection of asteroids less reliable at times.

Firstly, asteroids of all shapes and sizes have been observed. However, even the smallest can cause damage to Earth in one way or another. Unfortunately, the small asteroids, especially the ones that are distant or the ones that have dark surfaces, are difficult to detect as they do not reflect that much light. Spotting them against the darkness of space makes it nearly impossible. This problem requires extremely accurate and detailed instruments to detect smaller asteroids.

Asteroids travel at extremely high velocities across space, making it difficult to accurately track their motion from Earth, especially because they are visible in the sky for brief periods. Moreover, the field of view for ground-based telescopes is restricted. This makes them suitable only for observations of already known objects but hinders the tracking and detection of unknown objects. In addition to their tremendously high velocities, these asteroids are also only visible during certain short periods; this gives the researchers a short observation window (*The Hunt for Hazardous Asteroids: Challenges and Advancements in Planetary Defense, 2024*). These problems for ground-based telescopes are further exacerbated due to unpredictable weather conditions and seasonal changes.

Among the most significant challenges that astrophysicists face is the sun's glare. This is typically a problem relating to asteroids that are farther from Earth than the sun called Atira Asteroids. These asteroids go unnoticed and hide within the sun's glare, thereby remaining undetected; this increases the risk of collision with Earth. The sky in these regions is very bright, causing the sensitivity of optical equipment to reduce, which may eventually lead to damage to the optical equipment if directly pointed towards the sun. The previously stated incident at the start of the paper of the meteor explosion above a city in Russia was the Chelyabinsk meteor. This meteor approached Earth completely uninformed, which was primarily due to our blind spot in asteroid and meteor detection as a result of the sun's glare. We stand at the risk of similar asteroid impacts if this issue of the sun's glare continues to persist. More advanced equipment is required to overcome this issue, such as the space-based telescopes positioned away from Earth—the proposed Near-Earth Object Surveillance Mission (NEOSM)—could provide a better vantage point for observing sunward asteroids (*The Hunt for Hazardous Asteroids: Challenges and Advancements in Planetary Defense, 2024*).

The challenges involved in Artificial Intelligence and Machine Learning primarily include the quality of data. AI and ML are trained to analyse and identify based on a limited number of data points; thus, detecting and identifying real-world phenomena would be inaccurate and incomplete. Furthermore, the "black-box problem," or the inability to explain how a result was arrived at, has long plagued AI and ML. Lastly, there has been the everlasting issue of ethical concerns regarding the confidentiality of data and the constant fear of AI surpassing human control and "taking over the world" (*The Role of Artificial Intelligence and Machine Learning in Asteroid Detection,* n.d.).

There are various limitations and challenges in asteroid deflection. For example, in the Kinetic Impactor method, there are several factors that must be taken into account, including the composition of the asteroid, its size, mass, velocity of the spacecraft, etc. Moreover, executing this method is tricky, as in order for maximum deflection to occur, the spacecraft must collide with the asteroid in the direction of the motion of the asteroid. However, the rotation and shape can cause complications.

For Nuclear Explosive Devices, the main challenge would be the political and legal challenges. The Outer Space Treaty of 1967 prohibits placing nuclear weapons in orbit or on celestial bodies (*Defending Earth: Strategies for Deflecting Hazardous Asteroids, 2024*). Thus, even before considering any technical difficulties, it would be difficult to plan a NED mission in the first place. However, looking at the technical difficulties, the detonation of the bomb too close to the asteroid could lead to the asteroid disseminating into several tiny pieces that could eventually put Earth at a higher risk than before, as controlling several pieces of an asteroid would be more difficult and could lead to collisions all around the planet.

The Gravity Tractor method also has its limitations and challenges, even though it is the safest and most precise. This method is unsuitable for short-warning asteroids given that it requires a huge spacecraft and must be implemented for a long time. The spacecraft must remain in a position parallel to the movement of the asteroid. However, given the irregularities in the shapes, sizes, and rotation of asteroids, this is extremely difficult to maintain (*Defending Earth: Strategies for Deflecting Hazardous Asteroids, 2024*).

Future Prospects

ESA and NASA are working towards several upcoming projects that would contribute to having a robust future planetary defence. One includes "Test-Bed", an autonomous ground-based telescope under development with ESA, which will be placed in Spain and Australia. In place of the previously mentioned NEOWISE mission, NASA is now developing NEOCam that will serve similar purposes. Moreover, NASA is preparing the LUCY mission to investigate Trojan asteroids—asteroids whose average position is at one corner of an equilateral triangle formed with the sun and the planet Jupiter either eastward or westward of the planet. NASA's DART asteroid deflection project was a success. The impact of DART on the smaller asteroid that it diverted from its position will be observed by ESA's HERA satellite (*The Role of Artificial Intelligence and Machine Learning in Asteroid Detection*, n.d.)

Astrophysicists and aerospace engineers are working to devise alternatives or solutions to the present issues. There has already been progress; for instance, Lawrence Livermore National Laboratory has developed sophisticated simulation tools to model the effects of nuclear detonation on an asteroid's surface. These models consider factors such as the asteroid's porosity, the device's yield and detonation altitude, and the angle of incidence of the radiation (*Defending Earth: Strategies for Deflecting Hazardous Asteroids*, 2024). Moreover, there can be ways explored to minimise difficulties of the kinetic impactor method using an observatory spacecraft that accurately tracks the motion of the asteroid or using several different spacecraft, one after another, to keep on deflecting it further.

CONCLUSION

It can be safely concluded that our current asteroid detection and deflection technologies are not 100% reliable to ensure the safety of our planet. While there have been significant advancements in technologies right from the ground and space based telescopes to the gravity tractor method, and especially in the field of AI and ML, Earth's planetary defence, however, has a long way to go. One or two space organisations cannot single-handedly solve these issues, and all countries must work together to obtain a promising future for our planet. This research provides the readers with an understanding of the critical gaps in the already present technologies while also integrating the recent advancements. It builds on previous studies and space missions, such as NASA's DART, and examines how these technologies are applied in real-world scenarios while critically assessing their limitations.

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