Asteroid Detection and Risk Prediction for the Earth

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1. Abstract

Outer space surveys have obtained valuable information about celestial bodies which provides enough evidence to prove that majority of asteroids flow inside the asteroid belt between Mars and Jupiter and continue to move inside the same belt due to Jupiter gravitational force, however on occasion due to large planet's gravitational force asteroids get defected and become an impediment for other planets. Asteroids are rocky bodies moving across the sun and are too small as compared to planets. These asteroids are formed due to the collision of two gas clouds or planets, so they have abnormal shapes. Whilst an asteroid passes very near to the sun, it becomes hot and starts burning to provide light, this kind of burning asteroid is referred to as comets. Sometimes a small part of an asteroid or a comet, called a meteoroid enters the Earth's atmosphere and creates havoc on the earth's floor that is dangerous for life on earth. Therefore, it is a necessity to detect an asteroid coming towards the Earth and analyze its behaviors to avoid losses. In our work, we have worked on and analyzed asteroid detection in space and predicted risk to the earth surface, considering the parameters such as distance from the Earth, detected asteroid velocity, collision time and size of the asteroid. In the proposed research work, we have used deep learning concepts and astrometric calculations to gain greater accurate consequences. The research outcome shows the estimated risk imposed by the asteroid on Earth using the fastest single neural network, YOLO.

2. Introduction

The interest in the detection and tracking of Near-Earth Asteroids (NEAs) has grown dramatically over the previous few decades. There have been stories of stones falling from the sky throughout history, but it wasn't until the 1700s that scientists realized meteorites had an extraterrestrial origin. Meteorites have even struck humans in recent history. A tiny meteorite burst through the roof of an Illinois garage in 1938. A 5 kg meteorite shattered the roof of a house in Alabama in 1954. In 1992, a tiny meteorite destroyed an automobile near New York City. A 20 kg meteorite slammed into a two-story residence in uptown New Orleans in 2003. In India, a meteorite shower in 2003 destroyed numerous houses and injured 20 people. Lonar Crater is thought to have formed as a result of a meteorite impact. Lonar Lake lies roughly 137 metres (449 feet) below the crater lip and has a mean diameter of 1.2 kilometres (3,900 feet) [1]. Some of the celestial bodies cross the Earth's orbit posing the possibility of a collision at a future time. So, there is a need for the detection of such bodies to prevent collisions. At the same time, technology has also been increasing at an alarming rate, enabling well-known surveys and amateur mini-surveys to decorate their solutions to attain better predictions.

Based on this information presented in various surveys, we are making an attempt to use more reliable technology for detecting asteroids and predicting their collision threat to earth and its living being. Numerous attempts, studies, researches and software are made to locate near-earth objects. One of the most reliable ways to observe asteroids that approach close to Earth is to use radar, such as the device at NASA's Goldstone Deep Space Communications Complex in California [3]. A number of the preceding software like Astrometrica, Astrometry.net, SCAMP packages were developed for the detection of asteroids. Due to the destruction caused by previous collisions, we need to focus more on asteroid detection and risk prediction. So, in this paper, the related research analysis is done and a system is proposed using the latest technology. The objective of the paper are to make process fast and precise for detection and calculation of the risk factor. We have used YOLO which is an object detection algorithm. Predictions are made from one single network; it can be trained end-to-end to improve accuracy. In mAP measured at 0.5 IOU YOLOv3 is on par with Focal Loss but about 4x faster and processes images at 45 FPS and has a mAP of 77.9% [2]. The biggest advantage of using YOLO is its superb speed – it's incredibly fast and can process 45 frames per second. YOLO accesses the whole image in predicting boundaries. With the additional context, YOLO can demonstrate fewer false positives in background areas [4].

We have used YOLO which is an object detection algorithm. Predictions are made from one single network; it can be trained end-to-end to improve accuracy. YOLO is more generalized. It outperforms other methods when generalizing from natural images to other domains like artwork. YOLO algorithm is very versatile and can also be used in real time detection.

The structure of this paper is organized as follows. The first section provides background details and motivation of the research work. The second section describes the related work done in the field earlier. The third section is about our proposed architecture and methodology for asteroid detection. The fourth section of this paper explains the results obtained by our methodology and discusses it with comparison to previous work. The last section of our paper provides conclusions for our proposed research work and future improvements.

3. Related work

R Miehelsenl *et al* have presented amazing research about Asteroid and NEA detection models [5]. The Bering mission's findings on the populations of Near-Earth Asteroids and main belt asteroids are analyzed in this study. They looked at the Bering mission's scientific potential in respect to Near-Earth Asteroids and the Asteroid Main Belt. This is done by generating synthetic asteroid populations based on the most recent best estimates of asteroid size distributions.

P. Rajan *et al* have presented the work for Autonomous on-board near-earth object detection [6]. This research is looking at the potential of installing asteroid detection algorithms on-board a spacecraft, which would reduce the cost and time required to downlink a huge collection of pictures. The paper indicates that using quadruplets of picture data instead of triplets is critical in finding faint asteroids. The proposed pipeline's performance and run time make it an excellent option for deployment.

Greg Ushomirsky *et al* have presented the results of asteroid detection using a space surveillance telescope under Lincoln Near Earth Asteroid Research (LINEAR) Program [7]. The possibilities of SST for asteroid search are described in this work, as well as the approach for LINEAR search using SST and the new LINEAR SST processing pipeline. Recent modelling, observation, and detection findings, as well as system enhancements, are also presented.

H. Kabakchiev1 *et al* have shown the feasibility of asteroid detection using pulsar signals and have also provided power budget estimates [8]. This paper demonstrates that only pulsars with high flux values and pulse repetition with short periods may be employed in an FSR system for asteroid detection. The detection capabilities are determined on the kind of pulsar, the size of asteroids, and the reception characteristics of the radio telescope utilized. The results demonstrated that the predicted energy capabilities of a pulsar FSR system were insufficient to detect big asteroids at a distance of four hours before they entered the Earth's stratosphere.

Teodor Stefanut *et al* have demonstrated an algorithm for automated asteroids detection in astronomical images [9]. This paper describes a unique NEO detection technique created in the NEARBY research project and incorporated into an automated MOPS processing pipeline targeted at recognizing moving space objects using the blink approach. The automatic processing of astronomical pictures greatly decreases the time and human resources required for the discovery and ongoing monitoring of NEAs. Large datasets can be analyzed in near real-time, and steps to follow up on new discoveries or validate previously known asteroids may be done quickly.

Dorian Gorgan *et al* have explained the visual technique in Asteroids Detection Process [10]. This study will examine a visual technique based on image processing under various shades as an alternative to the presently utilized astronomical technique, which is based on calculation in the celestial reference system. One issue that has yet to be mentioned is the detection of asteroids that travel from one CCD frame to another in the mosaic of CCDs.

Zhihao Chen *et al* have presented work for real time object detection, tracking, and distance and motion estimation based on deep learning [4]. They created an algorithm based on the coordinates of the SSD method's output bounding boxes. The goal is to evaluate whether a pedestrian's or a vehicle's trajectory can lead to a risky situation. The entire process is being evaluated under real-world car traffic circumstances in Rouen city centre, as well as using footage captured by embedded cameras along the Rouen tramway. The paper offered a comparison of the SSD and YOLO V3 algorithms for object identification and tracking. A big and adequate dataset might be very significant for optimising their performance on low-consumption platforms. Changing the number of detection classes will not result in a substantial improvement.

Denisa Copandean *et al* have proposed automated prototypes for asteroid detection [11]. The findings were obtained using the blink technique, where a series of reduced images are displayed one after the other and the astronomer must pictorially locate legitimate motion in the series of photos This method becomes more challenging as the size of the CCD cameras multiplies. In order to replace manual detection, they have presented an automated pipeline design for asteroids sensing. Medium and large telescopes are needed to discover weak NEAs using the conventional "blink" technique, and this pipeline will be used for such data in the near future.

After the detailed study it has been noticed that the time taken for object detection was a major issue in previous studies and because of that lead time decreases, a threat to earth increases. Hence there is a need for improvement in the speed of the detection and more focus on reliability of the model.

4. Implementation

Previous research calculations, observations, stimulations and detections shows that there is a scope of improvement in areas such as sensitivity, accuracy and processing time. In this paper, preliminary steps are taken regarding image pre-processing.

4.1 Dataset

The proposed system requires the input of periodic space images of the night sky of a fixed area with a certain time lapse. For the parallax method, two datasets are required from the same position with a 6 months gap. Or datasets collected at the same time from a 180-degree revolution position. Include a separation of 2 astronomical units (AU) if two observations of the same asteroid on different ends of the Earth's orbit. At last, for determining whether the detected asteroid is known or not compare it with the catalogue containing necessary parameters.

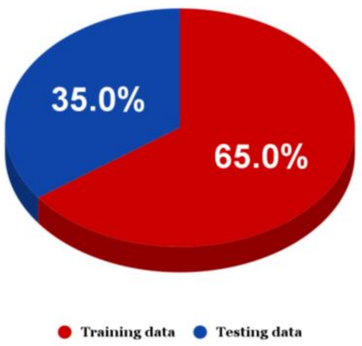

Fig. 1. Data splitting Ratio

4.2 Data Pre-processing

If the input is night sky images, then a Python library- Pillow, is used to remove background noise along with making adjustments to the scale by using registration and also for checking if the sequential images are of the same area. Now, these pre-processed images are suitable for the next process of moving object detection.
The proposed system requires a dataset, which is periodic space photographs of the night sky of a given area with a specific time-lapse. Two datasets from the same position with a 6-month gap are required for the parallax approach. Alternatively, datasets are taken simultaneously from a 180-degree revolution position. Include a two-astronomical-unit spacing if two sightings of the same asteroid are made at opposite ends of the Earth's orbit. Using the Python library Pillow, carefully proceed with image processing to remove background noise and modify the scale of each image by using image registration and also for checking if the sequential images are of the same

area. Now these pre- processed images will proceed for detection.

Input can be given as a sequence of night sky images for the proposed system, if the input is a sequence of night sky photographs, a Python module called Pillow is used to eliminate background noise and modify the scale of each image by using image registration. It will also confirm that the images present in the dataset are of the same area or not. These pre-processed photos are now ready for the next step of the moving object detection procedure.

4.3 Architecture

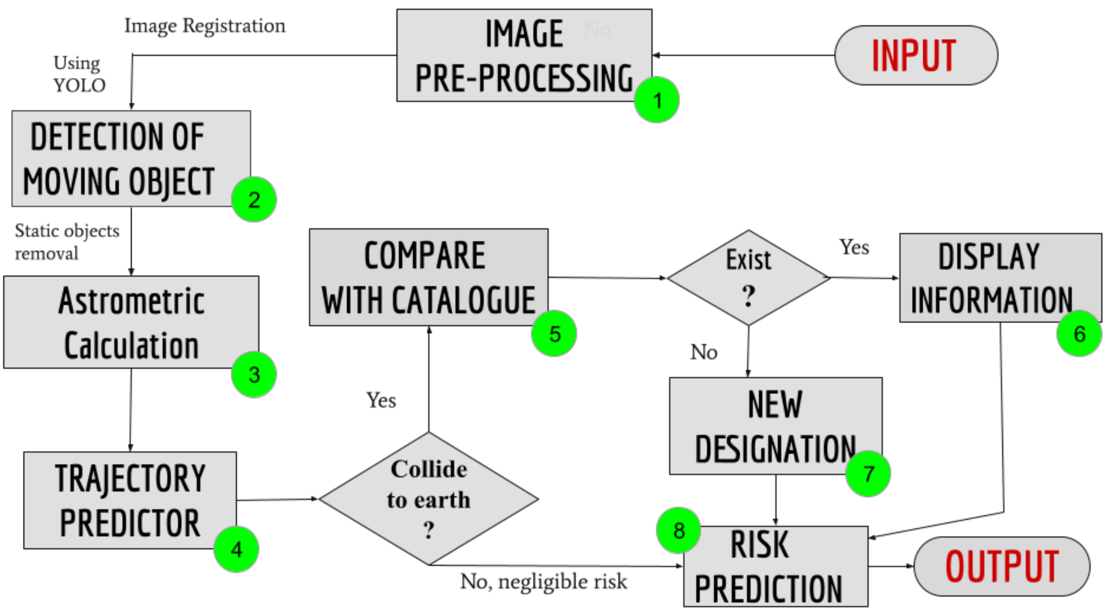

Fig. 2. Block Diagram of Proposed Methodology

4.4 Detection of Asteroid

After getting scaled processed images in the previous stage, the Detection part and also classification among unvarying and moving objects will be carried out using YOLO. After successfully detecting the asteroid, astrometric calculations are done to figure out the parameters such as Distance from Earth, Velocity of an asteroid, Size of asteroid and Time for collision.

Further Trajectory of the detected asteroid needs to be calculated so we can determine whether the asteroid falls on the earth's orbit or not. If the asteroid doesn't fall on the earth's trajectory so according to the proposed system, it poses a negligible risk to the earth. But if the trajectory of an asteroid falls on earth orbit it would be a threat to earth so we will predict the risk.

We have performed the experiment on google Collab using the free GPU. Imported darknet repository from GitHub for downloading pre-define weights. [12] Following Fig. 3 shows the flow chart of the system setup.

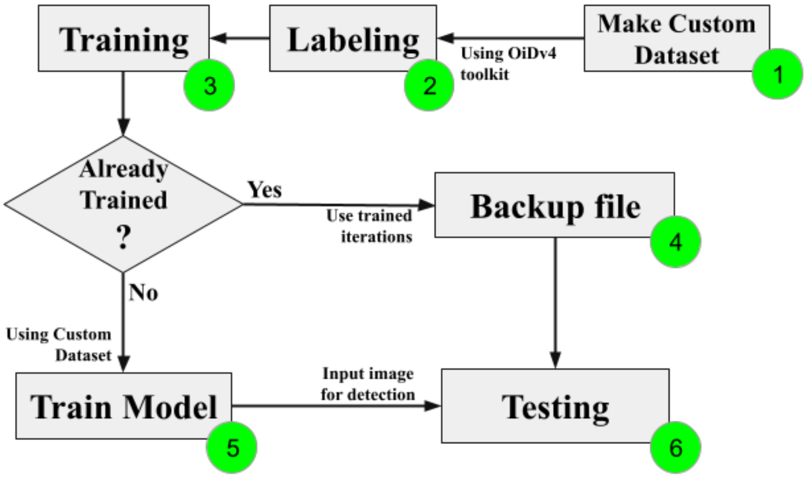

Fig. 3. Steps for data training and testing

a. Make Custom Dataset

- Identify the type of images needed for the training of models.
- Then make a custom dataset, first, collect images from various sites and save them locally in one folder.
- Remove irrelevant images from the folder if any.
- Make sure that each image in the dataset is of the same extension as others.

b. Labeling

- It is done by using OiDv4 toolkit which uses python library labeling.

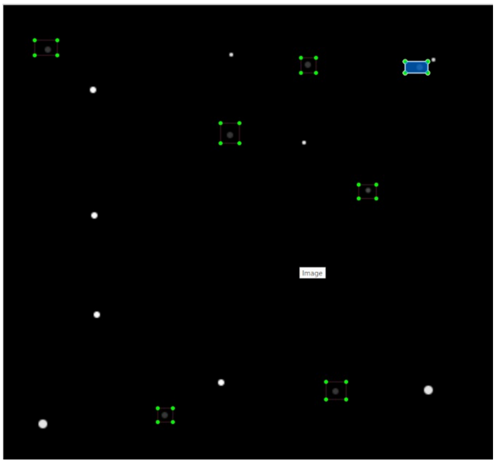

Fig. 4. Labelling using OiDv4 toolkit

- We have to manually make bounding boxes around each object and label them accordingly for all images.
- It will generate a text file with class id and image dimensions.

c. Training

- Use the dataset made in the previous module to train your model.
- If your model is already trained then follow module 4 in the next step.
- If your model is not trained yet then go for training as specified in module 5.

d. Backup File

- We have to create a backup folder to store the labels which have been trained
- After every 100 iterations a new file is made in the backup folder
- We can use the backup weights after the model is trained successfully.

e. Train model from custom dataset

- The model fetches the configuration file and trains the images according to given values
- It unzips the dataset and reads the text file generated in the labelling section
- It is recommended to train the model for a high number of iterations though the time required would also increase.

f. Testing images

- We can use images of any format or size for testing
- Store it in the right directory or else it would not show up.

Detection of asteroids now can be done using these preprocessed images. For detection, we are proposing the use of yolov4. YOLO, a proactive convolutional neural network (CNN) for object detection, is used for detection. The YOLO algorithm divides full images into regions called bounding boxes. With YOLO, a single CNN predicts numerous bounding boxes at the same time and assigns weights to those boxes as a probability. YOLO gives high accuracy and is extremely fast because of non-max suppression. YOLO works on full images and gives detection results. Here, yolo would identify a moving object by making bounding boxes around the object from the input and using coordinates of bounding boxes we can track the motion of those detected objects. If the object's bounding box coordinates are the same throughout the multiple frames, then it will be considered as an unvarying object else, it is a moving object and would be considered as a threat. After that removal of this unvarying object from the captured images, leaves us behind with celestial bodies that pose a threat to the Earth and life on Earth. At the end of a detection, we will be left with moving objects. We are assuming asteroids to be dim and smaller than stars in input images.

Fig. 5. Detected Asteroids

4.5 Astrometric Calculations

In astrometric calculations, we will be finding the risk factors such as distance from earth, velocity of the moving object, collision time and size of the asteroid.

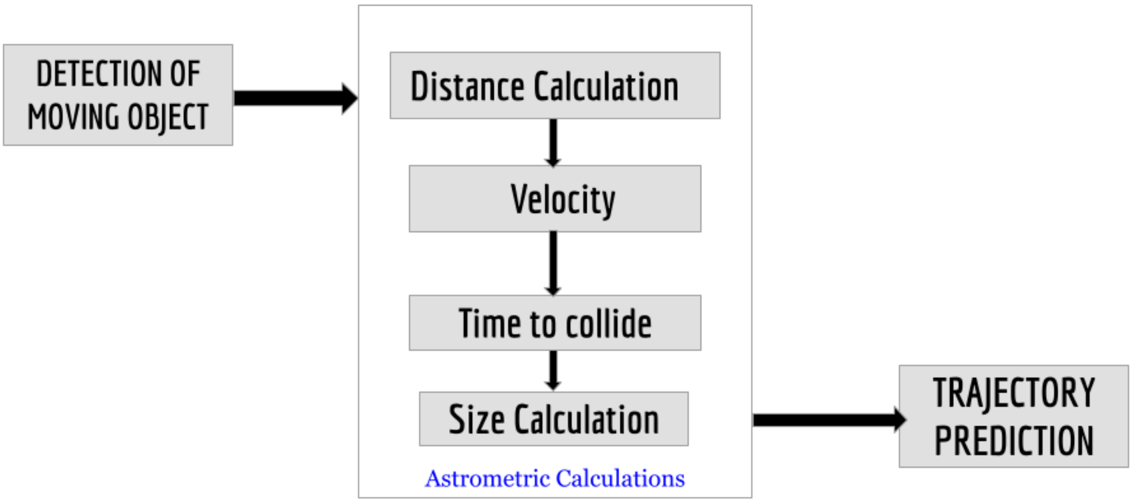

Fig. 6. Flow of Astrometric Calculations

4.5.1 Distance Calculation

For the calculation of the distance factor, which is the distance of an asteroid from the earth, we will use the Parallax method. The process of measuring the distance to an item by examining how it appears to move against a background using two points of observation is known as parallax. Parallax is the displacement or the change in the apparent position of the object when viewed from two different points of view. Observe the same asteroid from each location over time. Calculate the asteroid's location in relation to the field stars. Determine the ratio in the asteroid's apparent position between the two locations. Call that angular shift theta, the parallax angle.

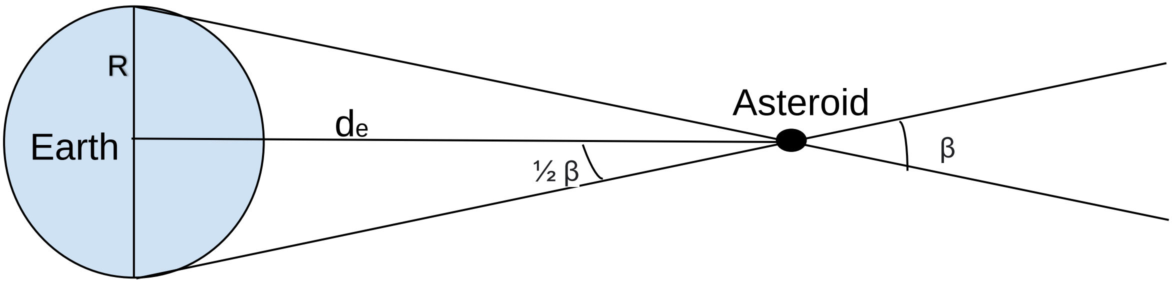

Fig. 7. Parallax method

This gives us a noticeable angle β between the asteroid's 2 apparent locations. To find the distance of the earth to that asteroid-

$$\text{Let, } 1/2\beta = \Phi$$

$$tan\Phi = \frac{1\ AU}{d_e}$$

Since the asteroid would be very far away, assume tanΦ is about equal to Φ that simplifies our formula for parallax as:

$$\Phi = \frac{1AU}{d_e}$$

$$d_e = \frac{1AU}{\Phi} \qquad (1)$$

Here,

d_e- Distance of asteroid from earth

Φ- parallax angle

4.5.2 Velocity Calculations

To find the velocity of an object we need relative displacement travel by an object in our input images. So, to find relative displacement we can use a coordinate system. For the first two images, we will fix the left-bottom corner as the origin. With respect to the origin, we can calculate the position of the object in the form of coordinates. Then using Euclidean distance, we can find relative displacement between the two points. After that, by using scaling given along with images we can find the actual distance travelled by an object in real-time. Then to calculate the time needed for calculating velocity we will use the time gap between periodic images given with the dataset. Now, we have both displacement and time consumed in that displacement, so by using the velocity formula which is displacement divided by the time we will find the actual velocity of the asteroid.

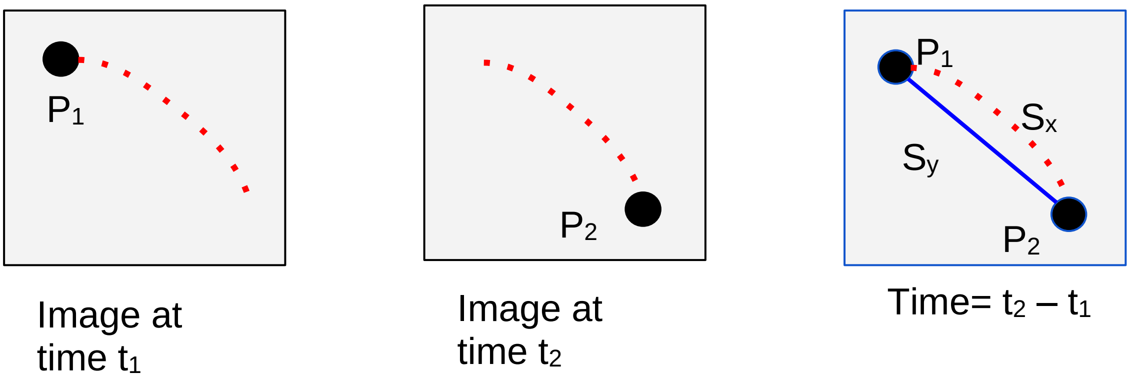

Fig. 8. Asteroid Movement

$$\textbf{Velocity of asteroid (V)} = \frac{Sx}{t2 - t1} \approx \frac{Sy}{t2 - t1} \qquad (2)$$

Here,

P_1 - position of the asteroid at time t_1

P_2 - position of the asteroid at time t_2

t_1 - time at which image 1 was captured

t_2 - time at which image 2 was captured

S_x - actual distance travelled by the asteroid in time t_2-t_1

S_y - Assumed distance travelled by the asteroid in time t_2-t_1

V - Velocity of the asteroid in time t_2-t_1

4.5.3 Time Calculations

To estimate time taken by an asteroid to reach earth surface will be calculated as total distance calculated using the Parallax method in the previous section divided by the velocity of the asteroid.

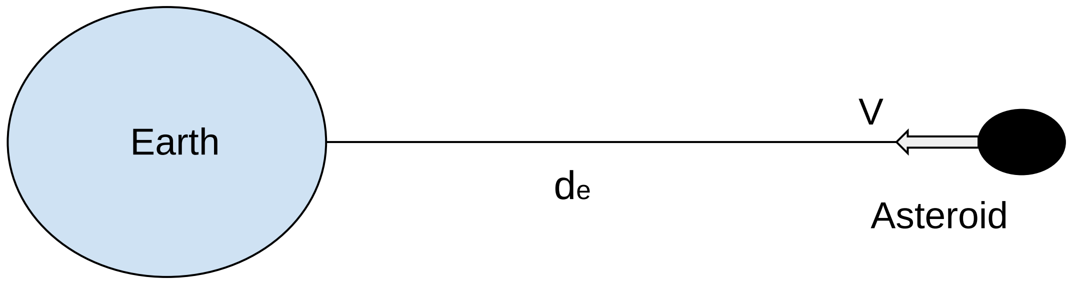

Fig. 9. Time calculation setup

$$\text{Time(T)} = \frac{V}{d_e} \tag{3}$$

Here,

V- Velocity of the asteroid

d_e- Distance of asteroid from earth

T- time taken by asteroid to reach earth

4.5.4 Size of the asteroid

The size of the asteroid is a major factor to predict risk. To calculate the size or diameter of the asteroid [13] we are going to use the following formula

$$\mathbf{D} = \frac{10^{-0.2M}}{\sqrt{l}} \times 1329 \tag{4}$$

Where,

$$\mathbf{M}\ (\theta) = m - 5\ log(d_e \times d_s)$$

Here,

D - Diameter

M - the absolute magnitude of the asteroid

l - albedo[1]

m - observed magnitude [2]

d_e- Distance of asteroid from earth

d_s- Distance of asteroid from the sun (assumed as 1AU)

θ - phase angle (assumed earth-sun-asteroid angle to be zero)

4.5.5 Trajectory Calculations

Now, in order to determine whether the moving object is truly hazardous to the Earth. A newly discovered body's trajectory will be calculated by using periodic images received from the camera depending upon the angle of inclination. For trajectory, we are following the concept of the Asteroid orbit Determination Project [14]. Here,

[1] Albedo of an earth crossing asteroid is assumed as 0.1 and its common range is from 0.05 to 0.25.

[2] The size of an asteroid as measured with a CCD camera using a suitable method to extract m.

equatorial points of the asteroid are calculated first and then determination of the orbital elements that will describe the asteroid's orbit.

Once the image data of the asteroid is collected, they need to figure out its equatorial coordinates, or where it was in the sky. Using The Sky Software, [15] they have determined the locations of reference stars surrounding the asteroid and in order to determine the location of the asteroid. After calculation equatorial coordinates, they have used Gauss's Method of Orbit Determination [16], programmed in Python, which takes the data from three observations to determine the six orbital elements, that are, Eccentricity, Semimajor Axis, Inclination, Longitude of the Ascending Node, the argument of Periapsis, Mean Anomaly. After determining these elements, they were able to generate a visualization of the orbit of the asteroid.

If the moving object's orbit does not fall into earth's trajectory, then it is not an asteroid and output will be zero risks. If it falls into earth's trajectory then it can be considered as an asteroid and depending upon its calculations, we will compare it with the catalogue. The next step is to gather information about the celestial bodies detected and compare it with an existing database so, if they match, we can actually save all the processing time we need for newly discovered bodies. Else, it will consider it as a new asteroid and the newly detected asteroid is given a new nomenclature depending on which category it falls into. This will help us to get knowledge of the body if it appears again in future. Further, we will find risk depending upon risk factors calculated in previous stages and will give an output of risk in percentage form.

4.6 Risk Prediction

For risk prediction, we will follow the threshold values given by the well-known space sources for factors calculated. Risk does not depend on individual factors, for risk calculation multiple factors are taken into consideration. Here, we are talking of four major factors which are, the distance of an asteroid from the Earth, velocity of the asteroid, size of the asteroid and time taken to reach the Earth. An effort is made to predict risk from three factors out of four factors. Following are the threshold values of factors responsible for risk.

Table 1. Risk Estimation Factors

Distance from Earth	**Velocity of asteroid**	**Size of asteroid**	**Risk**
-	-	<25m	Enter but burn
Less than or equal to 1km	-	>=25m	Hit
-	>=18 km/s	-	Do not enter
-	<=72 km/s	-	Hit
80 - 120 km	-	<=100m	Enter and burn

The proposed system predicts the risk of the detected asteroid on the Earth at the end of the procedure. This will help the user to understand the seriousness of the situation and according to the risk, planetary defence techniques can be implemented. This can save a significant amount of time while deciding on planetary defence measures by employing an automated approach-based selection of techniques depending on the range of risk levels.

5 Result & Discussion

Some celestial entities traverse through the Earth's orbit, raising the risk of a collision with the earth surface in future. As a result, there is a requirement for the detection of such bodies in order to avoid collisions. Motivated by research and analysis proposed in technical papers, we proposed a system where the celestial bodies are detected and the moving objects are filtered out which may intend to pose a threat to earth. In this research, we have used the latest technology YOLOv4 for more precise detection of asteroids from images. Since YOLOv4 is extremely fast and accurate, it looks at the whole image at test time so its predictions are informed by the global context in the image. It also makes predictions with a single network evaluation and hence it makes the process of detection more reliable and less time consuming. The main outcome of this system is an estimation of risk after acknowledging the asteroid. Risk is the chance of the asteroid colliding with Earth. Risk estimation is done on the basis of defined parameters explained in previous sections of the paper. The estimated risk is summarized in table 1. However, due to limited dataset our yolo model may not accurately detect some objects but it can be improved as we improve the quality of the dataset.

6 Conclusion

We have successfully identified a solution for the quick detection of an asteroid and the risk considerations associated with it are discussed. The YOLOv4 algorithm is used in the suggested pipeline, which processes 45 frames per second, which is faster than in real-time (24 frames per second). The suggested pipeline also estimates risk by considering threshold values for an asteroid's distance from the Earth, its velocity, the time it takes for the asteroid to reach the Earth's surface, and its size. The algorithms that are used are simple to comprehend.

There are various ideas and techniques for improving the provided answer, which will result in a more accurate estimation. In the future, improvements to the pipeline for estimating velocity can be made, since we are now assuming rectilinear motion of the asteroid, which may result in amendment for distance calculation, which impacts total danger estimate.

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