A 3D SIMULATION FOR THE FEEDBACK LOOP BETWEEN ORBITAL DEBRIS AND FUTURE SPACE ACTIVITIES AND ECONOMY

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ABSTRACT

Since the success of SpaceX's reusable launch system program, there has been a massive resurgence in interest in space, hundreds of companies and startups are racing to develop cheaper ways of venturing into the vacuum of space. As a result, the sustainability of the space environment will be put under great danger and pressure, threatening all other future space activities. In the study, we attempt to quantify the chain effect of various forms of space activities and orbital debris using Unity3D, followed by proposing the plan to use NASA's simulation software Orbital Debris Engineering Model (ORDEM) 3.0 and Debris Assessment Software (DAS) 3.0.

KEYWORDS

Orbital Debris, 3D Simulation, Unity3D.

1. INTRODUCTION

The space environment is experiencing the rapidly growing threat of orbital debris, defined by NASA as any object in orbit that does not serve any useful purpose. Examples include nonfunctional spacecraft, spent rocket upper stages, discarded hardware, and fragments from uncontrolled chemical explosions. Debris comes in a wide range of sizes, from less than 1 mm to larger than 40 cm in diameter; orbit, from circular LEO (low Earth orbit) to highly eccentric orbit that reaches beyond GEO (geostationary orbit); and velocity, from less than 3 km/s to 20 km/s. At such high velocity, impact with even minuscule debris can cause devastating damage to any spacecraft, an object with a diameter of 1 cm traveling at a relative speed of 10 km/s contains more kinetic energy than a .50 BMG bullet. As of January 2019, 94% of all catalogued man-made objects in space are debris, over 34,000 are larger than 10 cm, 900,000 are between 1 cm to 10 cm, 128 million from 1 mm to 1 cm, and likely many trillions that are smaller than 1 mm (ESA, 2019).

The danger of orbital debris comes from several factors, unpredictability, detection difficulty, large population, and exponential growth. First, debris is affected by minor forces such as atmospheric drag and gravitational perturbations that will slowly alter their orbit, the resulting orbit is difficult to calculate into the far future, making avoidance maneuvers tighter on time than maneuver with an object whose orbit is known ahead of time. Secondly, due to the tiny sizes of debris, most of them (under 1 cm) cannot be tracked by either ground telescopes nor satellite

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detectors, effectively rendering them invisible and impossible to avoid (Watson, 2015). Thirdly, the multitudinous distribution of debris surrounding Earth means that the collision rate is much greater since there are debris in wildly chaotic orbits, coupled with the fact that they are hard to detect and prone to unforeseeable changes, most spacecraft are sitting ducks. Finally, the problem is exacerbated by exponential growth, specifically, this phenomenon is known as the Kessler Syndrome, which describes the cascading growth of debris due to random collisions between the debris themselves. Models have shown that a relatively small amount of debris with very little inclination difference can spread out over time to become a massive band of debris encapsulating the entirety of Earth's celestial sphere (Rex, Eichler, Soppa, Zuschlag & Bade, 1989, p.107-120). Unfortunately, we may have already crossed the point of no return, the amount of debris in orbit has already passed the critical density for uncontrollable growth, meaning that even if we stop putting anything into space, the problem will continue to get worse. The Kessler Syndrome will be a key interest point throughout this paper.

Satellite operation within this dense sphere of debris is incredibly risky, yet in a modern world where society is so dependent on space technology, most are completely oblivious to the fact that the space environment has never been more at risk. The overcrowding of the space environment would greatly hinder human activity and the development of science in space. In this paper, we attempt to quantify these impacts using the Unity3d engine.

We used Unity to replicate a space debris simulation by using game objects to represent debris. The simulation contained a horizontal, vertical and diagonal band of space debris that copied the physics of outer space. Space debris spawns at a random location within their band space and its speed acts accordingly. The closer the debris is to Earth the faster it orbits and the further away it is the slower it orbits. We can see the effects of space debris incrementing by instantiating new debris every time the user left-clicks on their mouse. Each debris contains a box collider that helps us detect the number of close collisions. This number of close collisions can help us determine space activity.

2. RELATED WORK

2.1 Current situation

To understand the full scope of things, it is necessary for this literature review to first introduce the current scale of the problem. In the research compendium Limiting Future Collision Risk to Spacecraft (2013), a number of space organizations examine the complex situation of the future of space debris and its effect on space activities. By studying current data, future technological trends, launch schedules, modeling, and simulations, the current collision rate for a single satellite is around 1 in 1000 per its 15-year life cycle. This means that approximately two operational satellites and three defunct satellites are destroyed every year. However, these supposed collisions have not yet occurred thanks to better tracking technology and avoidance maneuvers.

2.2 Military activities

The earliest predominant purposes were military and national security and it remains so. However, no spacecraft is safe from debris, military ones are no exception, the crowding of the space environment presents both legal and military problems. The United States is more dependent on space than another nation, the threat of orbital debris to military satellites are threats of equivalent seriousness to the national security of the nation. At the same time, countless organizations and groups depend on military space assets to function, many of them integral and irreplaceable to society. There would be incredibly costly for military satellites to be damaged or destroyed (one may cost up to a few billion dollars), but more importantly, the shockwaves of their destruction would be felt by more than just the government, it could be everyone. Due to the nature of communication satellites' transmissions with each other, the loss of a single communication satellite may induce effects similar to that of a full-scale network shutdown. Lieutenant Colonel Joseph S. Imburgia of the USAF asserts that even a short timeout, the loss of communication capabilities could still represent a near-total inability for the nation to defend itself from any form of complications (Imburgia, 2011). In a hypothetical situation where a military satellite is destroyed by space debris but incidentally interpreted as an attack could significantly degrade international relationships and possibly lead to war (Grego, 2011). However, the United States and its allies are deeply in favor and interest to preserve the sustainability of the space environment that their safety is so dependent upon. Military efforts could be made to reduce collision probability or even actively remove debris from orbit, which will surely have influence on other space activities.

2.3 Commercial activities and the space economy

While the military may be the dominant purpose of space activity, space is quickly becoming a commercialized place with unlimited resources and possibilities. An assessment by Jeff Greason and James C. Bennett of the Reason Foundation estimates future commercial activities could become one of the largest industries generating tens of trillions of dollars, a monumental leap from this year's $350 billion (Greason & Bennett, 2019). Examples of commercial activities include satellite communication, space tourism, interplanetary transportation, asteroid mining, etc, all containing immense economic potential. However, space debris has the possibility to shatter all these economic possibilities by making venturing into space overly dangerous for any meaningful commercialization impossible (Weinzierl, 2018). The problem is massively exacerbated by the recent invention of reusable rocket technology, which has lowered launch costs across the board by a dramatic amount (Adrian and Hyman, 2018). This sudden breakthrough has caused major disruption in the aerospace industry, veteran and startup companies alike are rushing to lower the price of venturing into space further, lowering the price tags even more.

This technological success has resulted in a massive resurgence of interest in space, plans that were previously impossible are now within reasonable reaches. Due to both demands can capability, reusable rockets are now planned to be used to build satellite mega-constellations for the purpose of worldwide ultra-fast internet connection, such as the 600 from OneWeb and the 12,000 from SpaceX. If their plans do indeed come to reality, it would be one of the biggest technological achievements; while at the same time, the greatest catastrophe to the space environment. As the sheer size of the fleets would increase the already-congested orbit by more than six times, inevitably causing collision rates to skyrocket. (Virgili et al, 2018) (Le May, Gehly, Carter, and Flegel, 2018). Along the way, both the space economy and environment will certainly be affected, the extent of effect are also sufficiently understood, however, this paper will focus partly on the cross-effect between the two instead.

2.4 Scientific activities

Due to its unique environment, space is an important place for science, many satellites have been launched into space for various purposes. Today, humans use many items that were invented thanks to orbital sciences without knowing it, and clearly, we have a dependence on it. However, research shows that orbital debris is posing an increasingly large threat to all orbital scientific operations. As the largest spacecraft ever constructed, the International Space Station had performed a total of 25 debris avoidance maneuvers since 1999, while sustaining countless micro-impacts. In the future with an unmanaged debris environment, the orbital laboratory may no longer be able to avoid debris due to the extremely population and render uninhabitable, effectively abandoning one of the most prolific science labs we have (Johnson & Klinkrad, 2009). A slow-down in scientific advancement would directly hinder the progression of space-related technology. Other scientific spacecraft are also affected. Space telescopes, crucial for the purpose of astronomy as their location allows them to avoid atmospheric turbulence, light pollution, and various other factors that affect observation quality (Hotz, 2017). Earth observation satellites, which are heavily relied upon by environmental scientists and meteorologists to gather information on the surface of Earth, with considerable usage in a wide variety of sciences (Durrieu & Nelson, 2013). The limitations to experiment and test things in space will certainly induce a stagnation in the development of space-related technology, negatively affecting the advancement of astronautics.

3. SOLUTION AND METHODOLOGY

3.1 Overview of the Solution

In order to simulate and visualize the orbital debris effects, we have built a 3D simulation environment using the game engine Unity3D. We simplify the object 3D models by ignoring the modeling details, but the core parameters about the moving states of the debris, which allows to customize the simulation requirements.

3.2 Components

Unity is a game development engine that can be used to create simulations and games in two or three dimensions. In our case we used Unity to replicate a Space Debris Simulation. In our model, each color block represents an object in space. The red block represents a space debris that orbits vertically around the white cube which represents the Earth. The blue block represents a space debris that orbits on the horizontal axis and the pink block represents a space debris that orbits diagonally around the white block. In order to see more space debris, spawn the user must left click on their mouse. Depending on where these new space debris spawn their speed will act accordingly. The user can add as many space debris as they would like to see the effects of increasing debris. Every time the user left-clicks a new space debris is instantiated on every band.

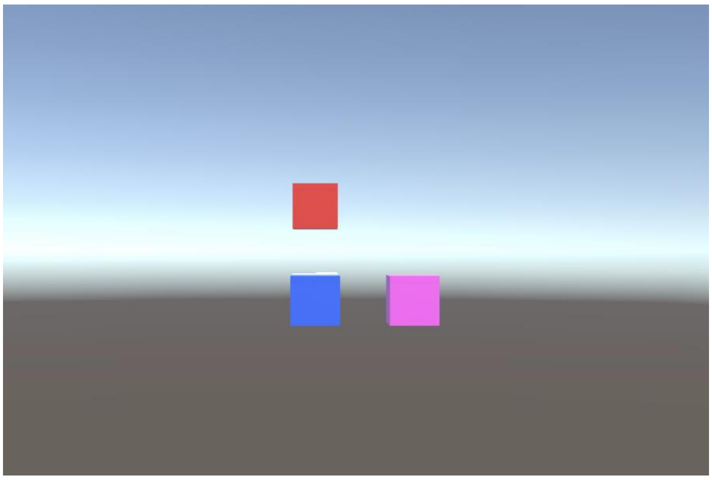


Figure 1. The initial state of the 3D simulation.

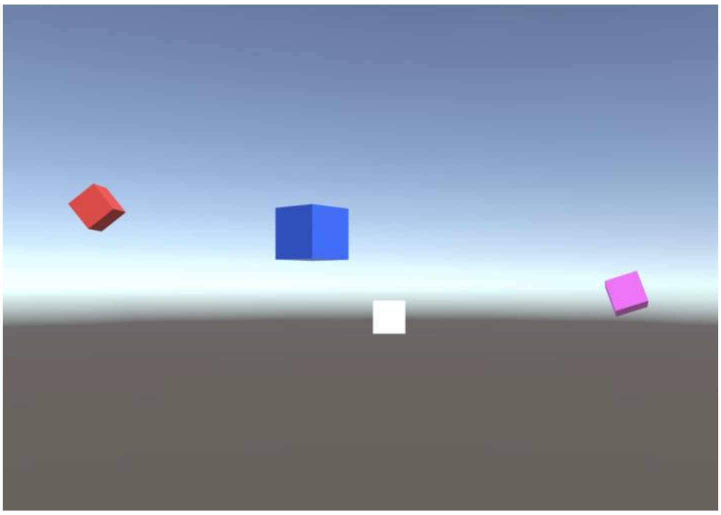


Figure 2. The moving state of the 3D simulation.

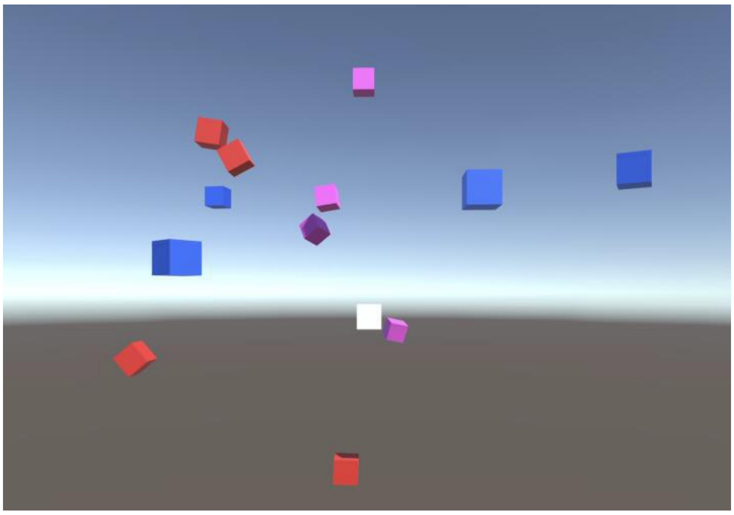
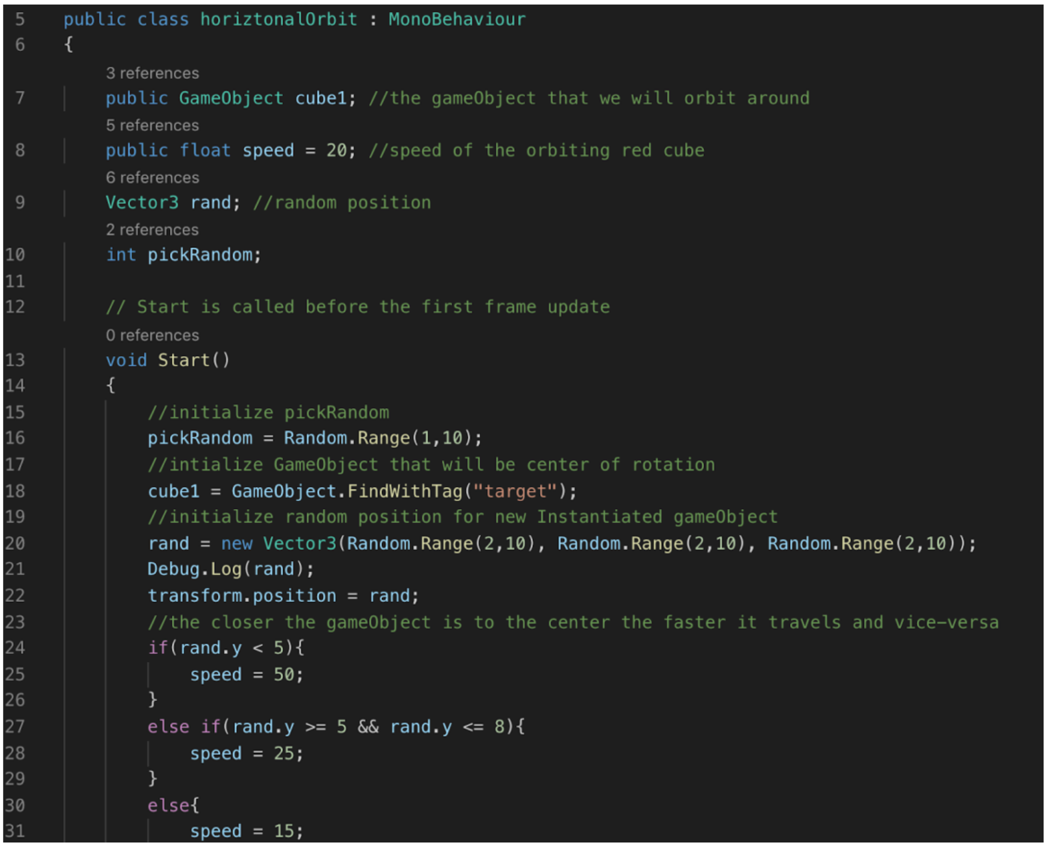


Figure 3. The increased scale of moving state of the 3D simulation.

Here are some screenshots of the code that makes this space debris simulation work. If you read the comments on the code it helps explain what each line of code does. Here, we made sure that our space debris orbits around the centered block which represents the Earth and is labeled “cube1.” We then initialize its default speed and in the “Start” function we set a random location for our debris to spawn within its specified band range. Next, we set the speed of the debris according to its y position. Every time a new space debris is instantiated, we then randomize its orbit. If the random number that is picked is less than or equal to five than the debris will orbit counterclockwise otherwise it will orbit clockwise.



```
public class horiztonalOrbit : MonoBehaviour
{
    3 references
    public GameObject cube1; //the gameObject that we will orbit around
    5 references
    public float speed = 20; //speed of the orbiting red cube
    6 references
    Vector3 rand; //random position
    2 references
    int pickRandom;

    // Start is called before the first frame update
    0 references
    void Start()
    {
        //initialize pickRandom
        pickRandom = Random.Range(1,10);
        //intialize GameObject that will be center of rotation
        cube1 = GameObject.FindWithTag("target");
        //initialize random position for new Instantiated gameObject
        rand = new Vector3(Random.Range(2,10), Random.Range(2,10), Random.Range(2,10));
        Debug.Log(rand);
        transform.position = rand;
        //the closer the gameObject is to the center the faster it travels and vice-versa
        if(rand.y < 5){
            speed = 50;
        }
        else if(rand.y >= 5 && rand.y <= 8){
            speed = 25;
        }
        else{
            speed = 15;
```

Figure 4. An excerpt of the Orbit controller code.

```
    // Update is called once per frame
    0 references
    void Update()
    {
        OrbitAround();
    }

    1 reference
    void OrbitAround(){
        if(pickRandom <= 5){
            //orbits around counter-clockwise
            transform.RotateAround(cube1.transform.position, Vector3.down, speed * Time.deltaTime);
            transform.Rotate(0,-1,0);
        } else {
            //orbits around clockwise
            transform.RotateAround(cube1.transform.position, Vector3.up, speed * Time.deltaTime);
            transform.Rotate(0,1,0);
        }


    }
}
```

Figure 5. An excerpt of the Orbit rotation code.

4. FUTURE WORK

The approach we used were based purely on 3D modeling and simulation from the models we have created from scratch. To get a better result, we have recently gained access to a model and simulation for the debris population growth provided by NASA's Orbital Debris Engineering Model 3.1 (ORDEM 3.1) and Debris Assessment Software 3 (DAS 3.0) model. For the future work, four runs will be conducted on both software, each with its specific setting to simulate the following:

- No spacecraft, no launches, debris only
- Business as usual (spacecrafts and launches)
- Launches with mild effort to mitigate damage and reduce debris
- Launches with significant effort to mitigate damage and reduce debris

Of each individual run, the following data will be gathered:

- Number of collisions
- The probability of collisions
- The number of close encounters
- Final debris count

Data will be assessed to estimate the collision probability for debris of other sizes, then the entirety of collision probability will be combined to calculate the total probability of collision over time. The total probability will then be used to qualitatively and quantitatively estimate the effect of orbital debris on spacecrafts and other debris alike.

5. CONCLUSIONS

The current situation regarding orbital debris is no doubt concerning, but nonetheless within our technological capability to mitigate. However, with the fast-approaching future of 5G network and global internet coverage, the usage of space will become precious and crowded. As demonstrated by our research and others prior, the overcrowding of the space environment will be disastrous to society in almost every way possible, and incredibly difficult so manage once the population reaches a critical number. The dynamic space environment and unpredictability of human actions make this issue all the more difficult. But the problem is not too late to manage, with extensive monitoring of rocket bodies and effective post-mission disposal by satellite companies will ensure a sustainable orbital environment for the future society.

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