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SOLID WASTE MANAGEMENT FOR SPACE DEBRIS

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ABSTRACT

At present, in addition to several thousands of satellites for various applications, there are more than 900,000 pieces from 1 to 10 cm in Earth-orbit. This has been estimated by the European Space Agency (ESA). Furthermore, as time passes, these satellites represent debris. Such accumulated debris threaten the daily uses of space-based applications satellites and future missions. The potential danger would persist unless the international space community considers the risks and join forces to mitigate the danger. Today, only ideas have been proposed by the various space agencies without taking much action. Each of these ideas deals with a specific size of debris. Thus, this paper proposes an integrated design to remedy the situation. It is a satellite with robotic arms, electromagnetic mesh and onboard radar to detect, collect, shred and sort most of the debris larger than 1 cm. This material can, thus, be used as a source of raw material in a novel "made in space program." It can be used as row material for 3d printers for metal and non-metals needed for the maintenance of the International Space Station (ISS) and other equipment of future space missions. This proposal is a premiere design and a start of a pilot model. Also proposed here is a recommendation for a sustainable financing model that can be established by space agencies by assigning a tariff for each future space flight. The tariff value could be determined based on, the extent of the mission's lifetime, the size of the satellite, and the purpose of the mission.

Keywords: Space debris; Earth Orbit; Mitigation; Recycling, 3-D printing, ISS

ادارة المخلفات الصلبة للحطام الفضائى

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الملخص العربى :

يوجد اكثر من ٩٠٠ الف قطعه من فتات المخلفات الصلبة التي تتراوح اطوالها من ١ الى ١٠ سم متر في مدار حول الأرض. تدور هذه حول الأرض إضافة الى الاف الاقمار الصناعيه التي تستخدم في تطبيقات متنوعة. مع مرور الوقت وخروج هذه الاقمار الصناعيه من الخدمه تمثل هذه ألأجسام حطاما يهدد الاستخدامات اليوميه للاقمار الصناعيه والتطبيقات الفضائيه والبعثات المستقبليه في مدار الأرض. هذا الخطر لم ينظر المجتمع الفضاء الدولي في المخاطر وحد الجهود للتخفيف من اثارها السلبي.

ولذلك فى هذه الورقه البحثيه تم اقتراح تصميم اولى بمراحل مختلفه لتجميع وتقطيع وفصل المخلفات من خلال قمر صناعي. يوجد في هذا القمر البيئي رادار داخلي لاستكشاف اماكن ونوع المخلفات باستخدام تكنولوجيا التحليل الصور. يقوم القمر المقترح بتحديد كثافه وكميه المخلفات التي يمكن التقاطها باستخدام اذرع الية وشبكه كهرومغناطيسيه ويبدا بعدها مرحله تقطيع وفرز وفصل الحطام الاكبر من ١ سنتيمتر لاستخدامه كمصدر للمواد الخام للطابعات ثلاثيه الابعاد في محطه الفضاء الدوليه لانتاج ادوات وقطع غيار للمساعده في صيانه محطه الفضاء الدوليه وغيرها من المعدات وقطع الغيار التي تحتاجها بعثات الفضاء المستقبليه.

المقترح هو تصميم مبتكر وبدايه لنموذج تجريبي يتم الاعداد له الان. كذلك تم اقتراح بعمل نموذج التمويل المستدام يمكن انشائه من خلال فرض تعريف لكل مرحله فضائيه مستقبليه. ويؤخذ فى الحسبان ان لكل قمر صناعي قيمته التعريفه وتختلف هذه حسب طبيعة هذه الرحلات والعمر الافتراضي للقمر الصناعي لاستخدام هذه القيمه في الابحاث وفي تجميع واعاده استخدام وتدوير المخلفات الفضائيه.

الكلمات المفتاحية :الحطام الفضائى , تدوير المخلفات , طابعات ثلاثية الابعاد , محطة الفضاء الدولية

1. Introduction

Each satellite in Earth orbit has an average lifetime of about five years. In addition, many satellites have been converted to small debris in various sizes. Such orbital debris is called space waste. It is also defined as: “human-made objects in space that are no longer functioning because of decays, deorbits, explosions, or collisions of satellites, and thus, create more debris. This debris remains in orbit and rotates above the Earth’s atmosphere. It survives for many years and might cause problems in the future if the space community does not take actions to deal with the potential risk.

The amount of the orbital debris has dramatically increased in the last decade due to increase and accumulation of parts of satellites that were launched from many parts of the globe as well as from accidental spacecraft explosions and collisions. Collisions of larger debris create numerous fragment clouds in the 1-kilogram mass range (David 2004) [2]. In the meantime, orbital debris could destroy any satellite. Over 1000000 objects ranging from 10 cm to 1 cm; are large enough to cause serious damage. Moreover, there are more than 330 million particles range from 1 cm to 1 mm in size (ESA 2021) [4] that could puncture a spacesuit and cause damage to fuel tanks or windows of space station and spacecraft.

Hundreds of million pieces of space debris in Earth orbit were generated from the space activities of only a few countries. This includes more than 300,000 pieces of space debris large enough to destroy operating satellites upon impact (Wright 2007 [12]; Johnson 2009 [7]).

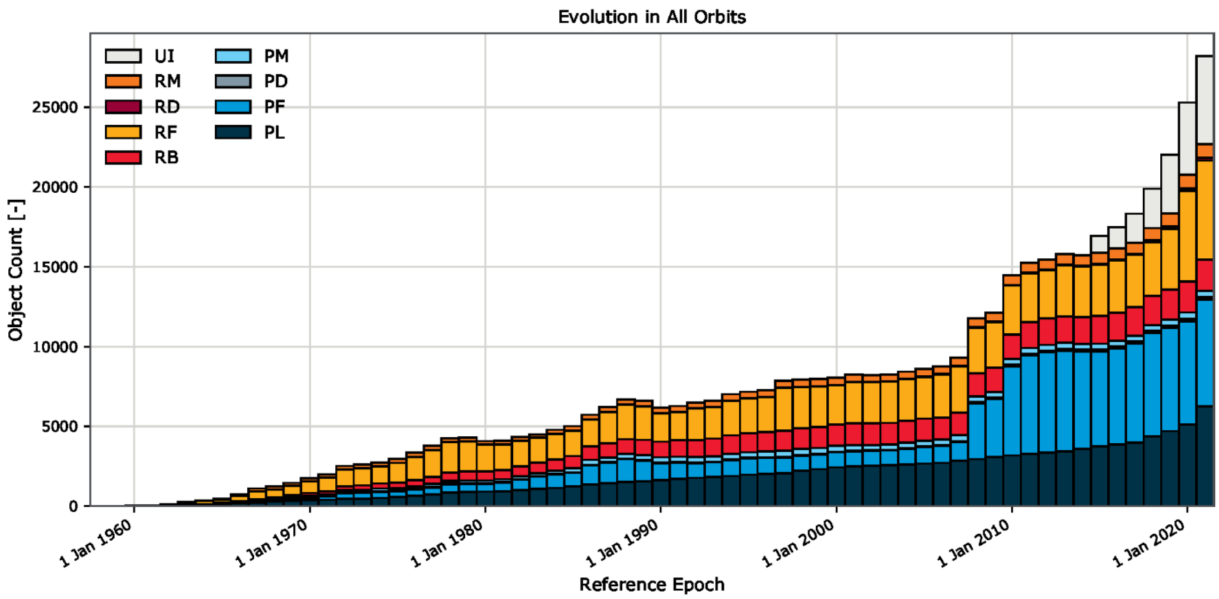

Figure 1:Space environment report ESA's 2021

Space debris is increasing dramatically in the last decades and increasing due to the enormous need for the number of commercial satellites launched to the near-Earth space (ESA's 2021) [5]. Many of these satellites are launched into large constellations to provide different services, especially communication services throughout the globe. Although these bring great benefits to our daily needs, they also pose a challenge to long term sustainability.

Thus, space debris increases the risk of terrible collisions of spacecraft and threaten human crews. Moreover, the increasing number of orbital debris threaten essential space-based applications, which are needed in our daily applications, such as weather forecasting and communications (Paul K. Martin 2021) [10].

This paper proposes a preliminary design of a satellite that can be used to collect various sizes of space debris. The latter can be recycled for use as a source of raw material in construction equipment, in maintenance of the International Space Station (ISS), or to satisfy other needs of future space missions.

1.1 Current activities of monitoring and tracking space debris

To decrease space risks, there is a need of careful monitoring, measuring and tracking the debris in Earth orbit. The Orbital Debris Program Office (ODPO) at NASA is taken the lead in conducting measurements of most of the orbital debris environment. It also has taken serious steps to invent technical consensus for adopting mitigation measures to protect the space missions. The ODPO collects its measurements from 3 main ground radars (HUSIR, HAX, and Goldstone) by collecting and analyzes all the data using modeling applications to depict the space debris. However, the operating time of these radars were limited due to lack of funding for this program.

NASA cannot measure orbital debris below 3 mm in the most congested region (of the 600 to 1,000 km range) by using ground-based radars or telescopes. These particles are too small and too far away to be detected by ground-based radars such as HUSIR, HAX, and Goldstone, or through the U.S. Space Surveillance Network.

1.2 Mitigation efforts for debris removal

Space debris mitigation and removal efforts have become primary goals of a safe space environment. It is clear to everyone especially for the current operational satellites that are required for space applications used in our daily lives. People everywhere realized this when they considered rare Earth orbit for satellites required for weather forecasting, communications and Global Positioning Systems (GPS). All such knowledge is dependent upon the continued clean health of the satellites in Earth's orbit as well as for future missions to space.

Thus, the world’s space agencies are considering applicable solution to the collection of space debris. As an example, NASA has funded programs to demonstrate the uncontrolled deorbiting of spacecraft, as well as early-stage studies of active debris removal concepts, such as CubeSats, using NASA's Exo-Brake Parachute that increases the spacecraft's resistance to the braking device. Also, NASA is working on robotic refueling technologies to extend missions duration and relocate or deorbit satellites (Paul K. Martin 2021) [10].

NASA has also developed a program to send the first 3-D printer used a fused filament fabrication (FFF) process. The 3-D printing in Zero gravity to produced dozens of parts, this technology will provide a new logistics system for long duration missions. This project was designed to solve the problem of the lack of space in the ISS, which used to be the home of astronauts for more than nineteen years. the 3-D printer will help reducing the large number of spare parts required by missions as its required now sending more than 7,000 pounds of spare parts to the ISS annually.

Thus, this article shows the potential of utilizingrecycled material for printer feedstock. Recycling technology using 3-D printer also could make use of material that otherwise would represent a trash disposal problem for space missions. In addition, the In-Space Manufacturing (ISM) project is working on developing higher-strength plastics to be used in special 3-D printers in space (NASA 2019) [8]. A new metal 3-D printers introduced by Meltio can be used in printing metal parts in space using Single and Dual Metal 3D Printing (https://meltio3d.com/) [9].

Figure 2: Clearspace-1 satellite (ESA 2019)

The European Space Agency's (ESA) debris removal mission (ClearSpace-1), estemated to launch in 2025 (Figure 2). It consists of an armed robot that would latch onto debris and return earth, where both machine and debris will burn up by entering the atmosphere. The first mission will target a large piece of debris an upper stage leftover since 2013 (ESA 2019) [3].

The Japan Aerospace Exploration Agency (JAXA) has introduced a debris removal mission designed to launch in two phases in 2023 and 2026. The first is designed to "approach and observe." The second phase is designed to follow-up "observe, approach, capture, and retrieve". The intent is to collect a large discarded in the upper stage of a Japanese rocket selected for removal.

Also, JAXA is working on a novel project to construct the first ever "debris prevention" device . This new technology involves an electromagnetic tether mounted on a miniaturized satellite prior to launch. At the end of the mission, it would extend into the space, to interact with the earth's magnetic field, and cause the satellite to slow. This will results in the lowering of its orbit in a short period of time. Thus when it reaches the earth atmosphere (figure 3) the satellite would burn as it falls. (JAXA 2020) [6].

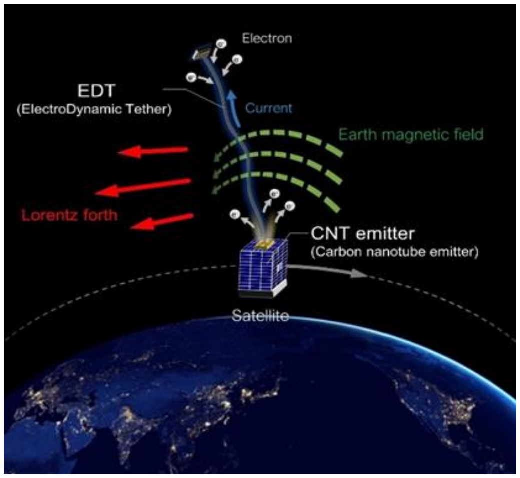

Figure 3: JAXA electromagnetic tether (JAXA 2020)

2. Methodology

2.1 Proposed Preliminary design of a satellite for real time detection, collection, and recycling of space debris.

The collection and recycling system proposed in this paper was designed to make use of the space debris as a source of raw material. Italso assumes that it could be used for construction equipment for maintenance of the ISS. Such a satellite can also be used for aequipment needed by the space missions as well as spacecraft of the future.

The proposed Preliminary design for the collection and recycling system as illustrated in (figure 4) directly helps the aim of the ISS program. The latter was introduced by NASA for use of 3-D printers in space to supply the needs of the ISS equipment (Paul Lim 2021) [11]. The latter were required for maintenance due to the lack of space in the ISS to store all spare parts. Therfore, the proposed design will help to decrease the number of missions required to send equipment and spare parts to the ISS.

Thus, the proposed design is a hybrid system. It works in line with the goals and serves the (ClearSpace-1) program of ESA and the JAXA. The use of an electromagnetic tether for space debris collection would save time, effort and funds required for future operations. Thus, future missions woul not waste resources by burning of the debris as it falls into Earth's atmosphere.

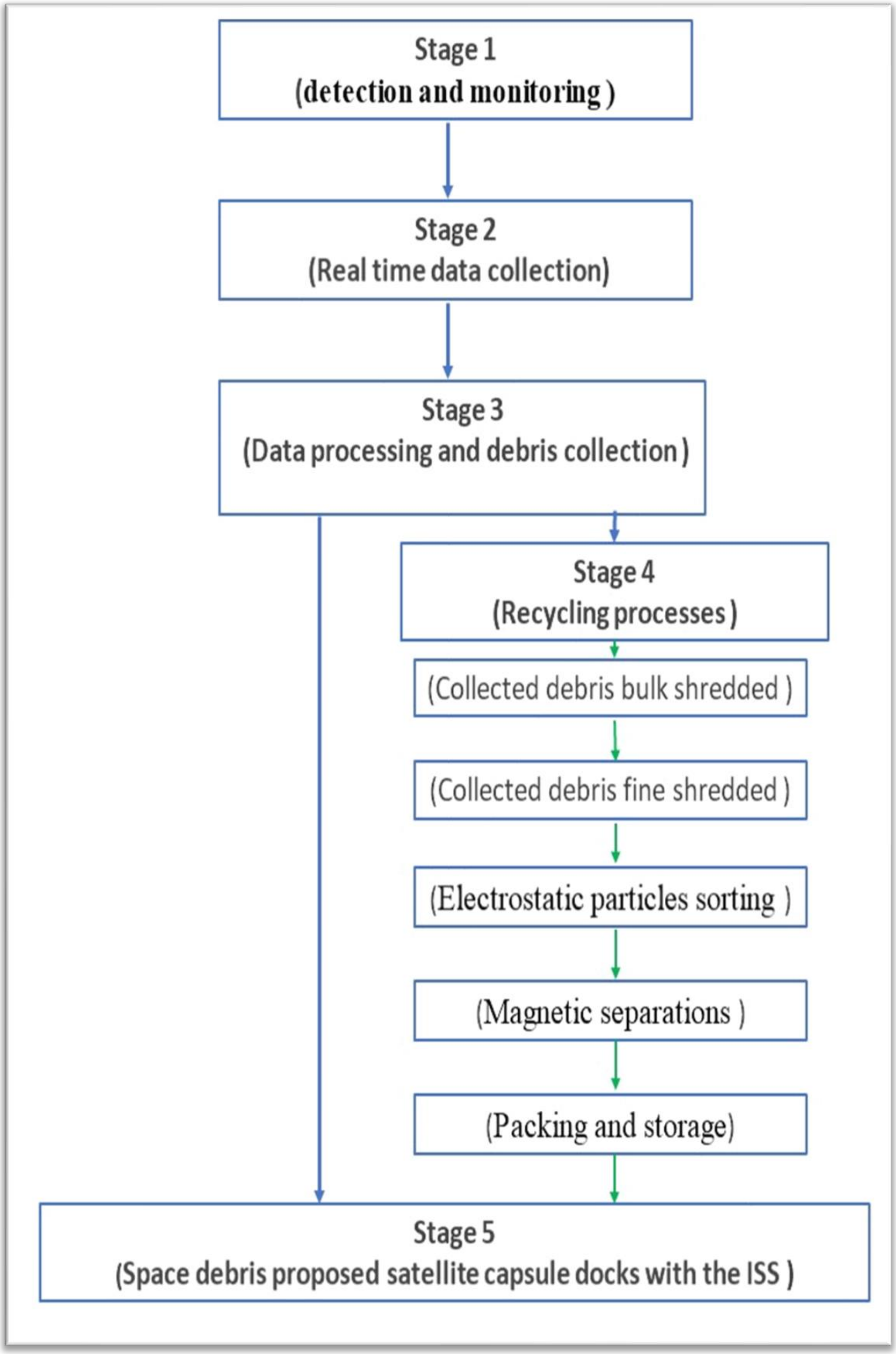

Figure 4: design stages flowchart

3. Result

3.1 The proposed system can be divided into five stages:

3.1.1. First stage: The ground radar sensor.

This sensor is designed to detect the clouds of space debris and send triggers to the space debris collection satellite to fly toward such debris.

These ground sensors should be well distributed throughout the world for an integrated work between the countries. The widely used rotated parabolic antenna design has been recommended for such contribution by using X or C bands radar signals (figure 5).

Figure 5: Ground radar

The realtime processing of the returned radar signals will differentiate between the objects that are located within the atmosphere and those located outside and totally different from the well –shaped space crafts or satellites. The backscattered echo from random and very far objects might be that of space debris. It would be defined as such, and sent to the space debris collection satellite to fly toward the debris for more detailed imaging using the onboard radar sensor.

3.1.2. Second stage: The Onboard radar sensor.

After the satellite receives an order from the ground station to fly toward the cloud of space debris, the onboard radar sensor will transmit its own signal with shorter wavelength (X band) to detect the small size particles of debris. The returned radar signals would also be processed to get more information on the dielectric constant of the debris. This information would be used to classify metallic and non-metallic objects for further sorting and usage (figure 6) .

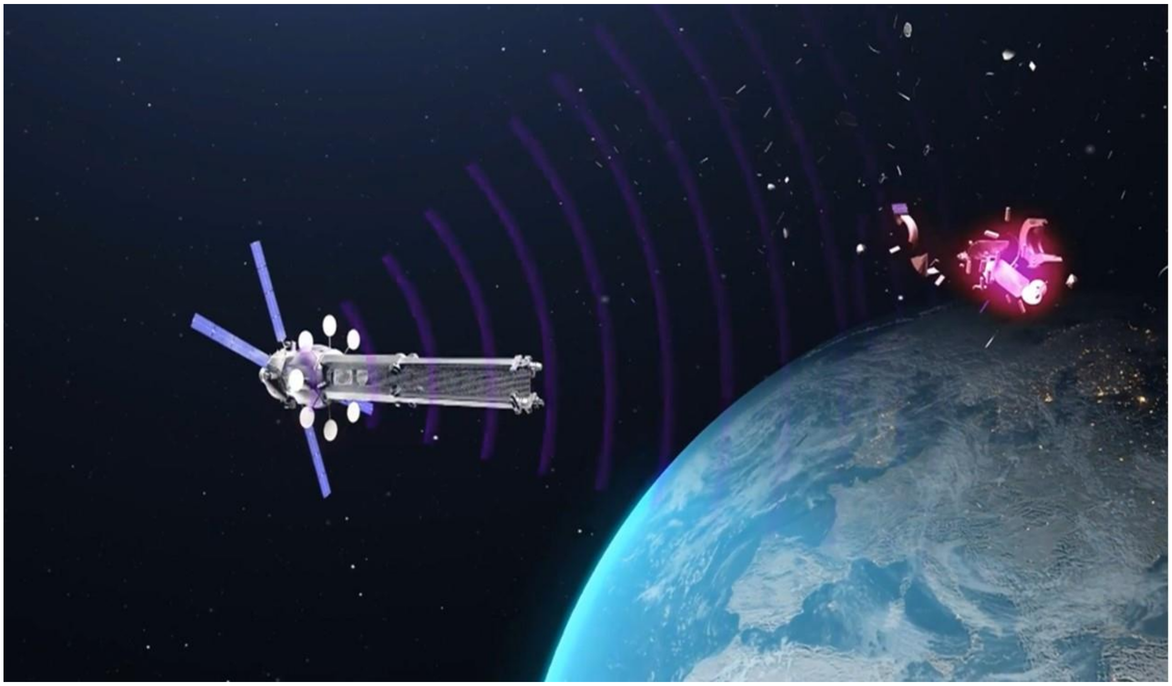

Figure 6: On bord radar transmitting signal

3.1.3. Third Stage: Data processing and debris collection.

The real time detection and data processing (figure 7) would provide accurate information on the density and the size of space debris and type of waste. This data would be analysed using image prosessing techniques to select the area for debris collection.

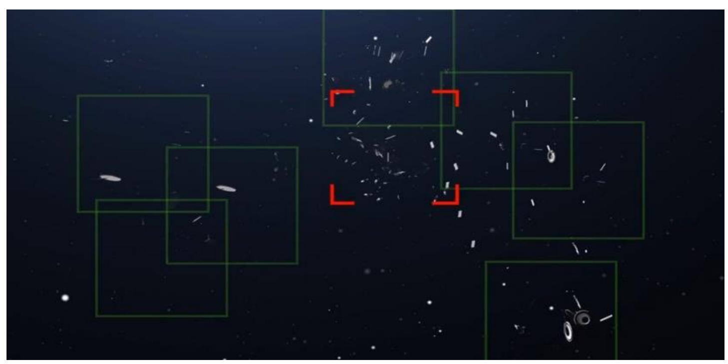

Figure 7: Radar data processing

In addition the space debris collection satellite would require proper information on the exact distance between the debris and the space debris collection satellite in order to fly toward the debris to fold and unfold the needed parts (figure 8). This allows collection of the calculated amount regarding the mesh volume for particles more than 1cm in diameter, i.e., materials needed for recycling.

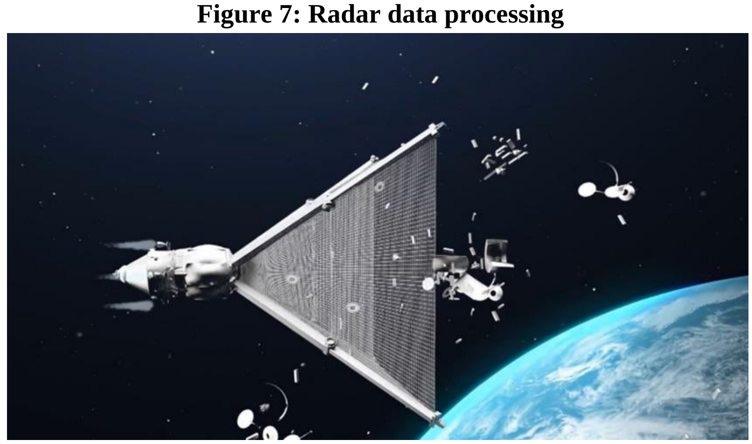

Figure 8: collection of space debris

The robotic arms with the flexible electromagnetic mesh would be closed to contain the space debris within the net. During that stage the space debris collection satellite would unfold the needed parts required to continue the journey to the ISS. During that journy, the collected debris would be prepared to be recycled as illustrated in the fourth stage (figure 9).

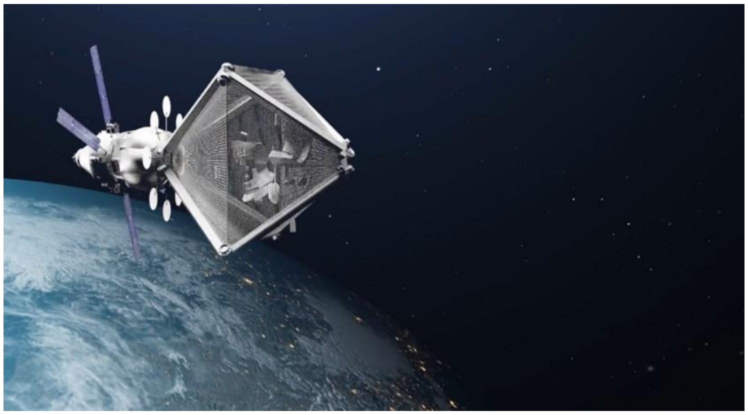

Figure 9: Robotic arms & electromagnetic mesh closed to contain the space debris

3.1.4 Fourth Stage: preparing the debris to be Recycled.

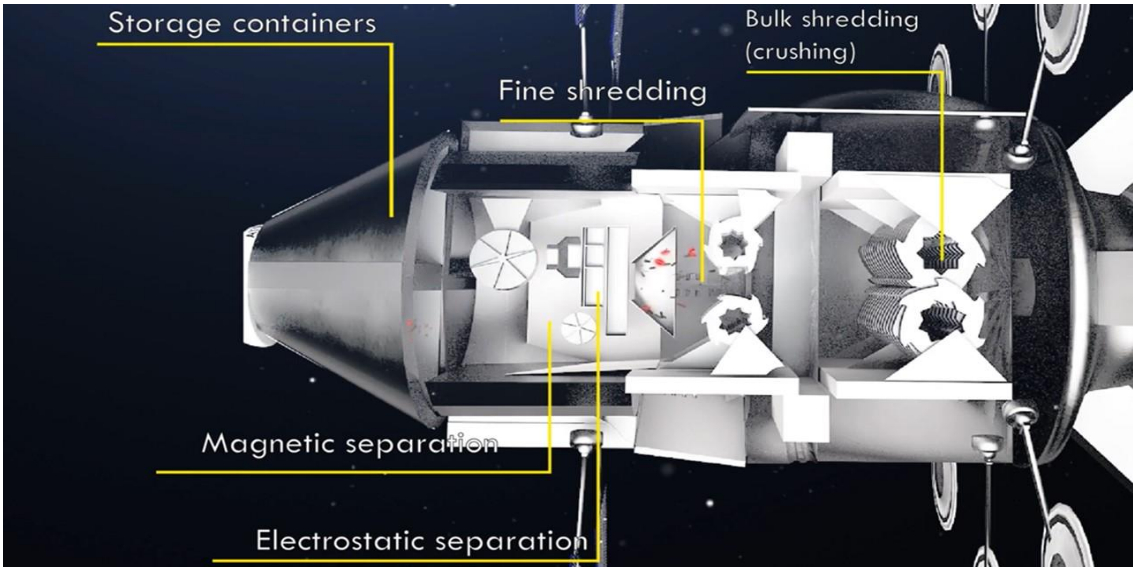

Figure 10: Shredding, sorting and storage of space debris inside the Proposed Preliminary satellite design

- **Shredding prosses inside the satellite during the journey to the ISS**
  To complete recycling of the collected space debris it must be first shredded on two stages bulk shredding then fine shredding (Figure 10) to reach a suitable size (powder) required for 3d printers used by ISM project by NASA and Meltio company for printing metal parts.

- **Electrostatic particles sorting**

  The debris, after being shredded to the desirable size, an electrostatic process is to be started. This type of separation is selective sorting of electrically charged objects using the electric field forces: for example, separating Metallic particles from nonmetal particles (Figure 10).

- **Magnetic separations**

  This process is used to separate paramagnetic materials (those that are less affected by magnetic fields, eg., gold, silver and aluminum) from ferromagnetism/ferromagnetic materials (those strongly affected by magnetic fields) as shown in Figure 10.

- **Packing and Storage**

  Packing and storage processes are the last to occur in the satellite during its journey to the ISS. Thus, sorted materials are stored and packed inside containers to be used as raw materials for the 3D printers in the ISS (Figure 10).

3.1.5 Fifth Stage: Space debris satellite capsule docks with the ISS.

At that stage the space debris collection satellite capsule docks with the International Space Station (Figure 11). The stored fine shreded powder is sorted for use as raw materials for the 3-D printers from the ISM program by NASA and metal 3-D printer from meltio to print equipments and spare parts for the maintainence of the ISS station and other long- time missions.

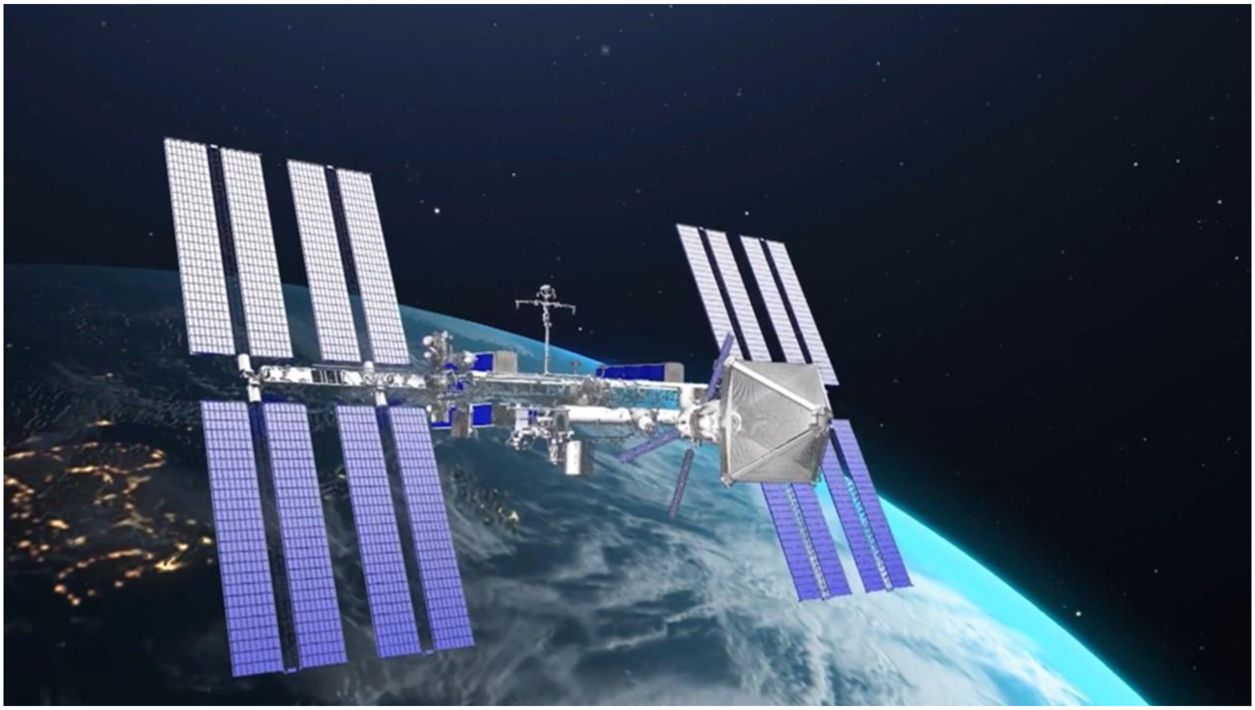

Figure 11: proposed satellite capsule docks with the ISS

4. Discussion

It is extremely important to overcome the problem of Earth-orbital debris by its collection and removal from space. This floating debris could have negative and dangerous impacts as it represents a hazard to current operating satellites as well as to future manned and unmanned missionin Earth-orbit. Therefore, it is urgent to introduce unconventional solutions to this potential problem. Efforts shoule be made by all space agencies to reach the most effective means and techniques for collection and recycling of space debris. The propsed method allow resuse of part of that debris. This is safer than wasting it or letting it burn in the atmosphere. This would be more useful than the RemoveDEBRIS project. In the later, a drag sail developed by the Surrey Space Centre would pull a spacecraft into the Earth's atmosphere and force the satellite to deorbit in approximately eight weeks (Airbus 2021)[1]. Such space debris represents hundreds of millions of dollars to future space manufacturing in space. Thus, there is a great need to develop a mechanism for the collection of space debris and its recycling for use as matterial for 3-D printers in space.

5. Conclusion

This paper proposes a preliminary design of a space debris collection satellite with robotic arms, electromagnetic mesh, and onboard radar to detect (in real time), collect, shred and sort most of the debris - larger than 1 cm - as follows:

1- Detection of space debris clouds using onboard radar sensor to determine the exact location, size, and components of the space debris in real time.

2- Collection of accurate information on the density and size of space debris components and type of waste for analysis using image prosessing to select the required collectoion area.

3- During the collection stage, the robotic arms with the flexible electromagnetic mesh would be used to collect debris particles larger than 1 cm of space debris.

4- In the shredding and sorting stages, the space debris will be shredded to fine particles and sorted using Electrostatic and magnetic separation rotating wheels. These would separate metals from nonmetal particles for use and recycling in the ISS using metal and plastic 3-D printing technology.

5- Raw materials Storage stage: the product of shredding and separation of particles will be stored in special containers. This would be used as raw materials in the manufacture of tools and equipment necessary for the maintenance required for the ISS station and other long- time missions. It is believed that this can be done using 3-D printing technology in the International Space Station (NASA's Space Manufacturing Program). Reusing this space debris is very important to save time, effort, and funds for future operations and missions.

6. Future recommendations:

1- The proposed design is preliminary and should be considered as a seed for a project to construct a full-scale pilot model during the year 2023 as a joint project by October 6 University in Egypt and Port Said University.
2- This research article is an invitation to establish companies by space agencies to specialize in the collecting, recycling, and reuse of space waste.
3- The required funds for the cleaning of the near-Earth space and recycling space debris can be provided by setting a tariff on each future space mission. This could, for example range from 3 to 5% of the mission cost. This percentage can be later be precisely determined based upon the expected lifespan of the satellite and the purpose of future space missions.

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