# ADHESIVE FLORA GRIPPER WITH CLAWS FOR DEBRIS COLLECTION IN LOW EARTH ORBIT

**Nivetha C**

*Corresponding Author Email: niivethachinnasamy@gmail.com*

---

**Abstract -** There are around 10,000 satellites in low earth orbit which will be increasing at a rate of 2400 more satellites per year. Collisions in Low Earth Orbit (LEO) take place at a speed of 9-14 km/s.Space debris have been a vigorous factor of space mission failure and collisions in space.There are around 128 million fragments of debris particle in the size of 1 mm to 1 cm and around 9,00,000 particles in the size of 1cm to 10 cm. This paper presents a basic ideology of utilizing a 3-dimensional floral shaped adhesive gripper functioning with electrostatic force to grab the debris below 10 cm in LEO in an effective manner.Each petal of the flower works autonomously beyond the variation of stress conditions of other petals and tested under various temperature and microgravity condition bringing out a success rate of 78% to 80% of noncooperative target capture.It focuses on the thermal and static stability of the gripper enhancing it to function regardless of unpredictable conditions in space.

## 1. Introduction:

Space debris is the expired and non-functional material wandering in space that are artificial and are mainly composed of defunct satellites, failed space missions, paint flecks, micro and macro particles formed during collisions and other debris formed due to human activities. As the maximum number of satellites are launched in Low Earth Orbit (LEO), theconcerns about the existence of space debris which may lead to collisions in upcoming missions and density of space debris is approaching a safety threshold in the space environment.So it is essential to focus on cleaning and removing the count of debris. Space debris mainly includes non-cooperative materials, micro and macro particles which are framed of different size, shape and speed.Predicting the factors of debris is a challenging one but it has to be collected and removed in order to get rid of space pollution.

Gecko inspired gripper, which was designed by Stanford developers is adhesive in any conditions due to the presence of several microscopic hairs called setae in its foot. It was bought by generating Van der Waals force providing adhesion.This paper is going to be based on a floral shaped adhesive gripper which consists of five or six petals where each petal is electrostatically adhesive and has its autonomous gripping mechanisms.The disk part of the flower which is the

focus will contain the power system and distributes power equally to each petals. Petals are made with claws at each end so that it works on holding the captured target accordingly. Certain amount of electrostatic force is created in each petal so that the escape velocity of the debris is less than the electrostatic force.

## 2. Key Components:

The gripper is designed in the model of a flower containing a central disk and a few petals of 3-Dimensions so that the contribution of each petal counts in the functioning of the gripper.

### i. Central Disk:

Initially its disk is designed as a pentagon and this is the part where the batteries and antennas are placed. The base of the disk is made of Aluminum-lithium(Al-li) alloy due to its durability, resistance to heat, ductility, damage tolerance, low mass density and elasticity.

### ii. Batteries:

Batteries are the main components providing power supply to the gripper. Several kind of batteries can be utilized but Comparing the nickel-cadmium and lithium-ion batteries, lithium-ion batteries are best suited since it has wide adaptability to resist in temperature conditions, easy to recharge using solar energy and stores the absorbed charges as it can be used later. It deliver up to 3.7 volt per cell and when four cell are connected in series, the voltage delivered is up to 14 volts. When the batteries are made according to cell chemistry and cell processing, the durability of cells have a cycle life of 60,000 cycles at 25% depth-of-Discharge (DOD).

A series of four lithium-ion cells are connected in series for each petal to deliver a stable power supply of average of 14 volts. It is connected with panels so that it can be recharged using the solar energy and the excess energy absorbed is stored in the cells which can be utilized in absence of power supply.

iii. **Sensors:**

Next, the major contributors are the sensors. The system uses simple obstacle identifying sensors like Radio Detection And Ranging devices (RADAR) and Light Detection and Ranging devices (LiDAR). RADAR are the primary contributors of identifying the obstacles as it can sense the debris even at long distance. Phased array RADAR's are used as the sensors and they can detect the target up to a distance of ~1,000 kilometers. It uses multiple antennas steering the beam at different directions without any need of physical movement in the antennas. ISRO's MOTR (**Multi Object Tracking Radar**) can also be a well suited RADAR for detecting the target at a distance of 800 km altitude. For the RADAR communication, the antenna of the receiver is fixed at the disk of the flower. The radio waves from the transmitter is spreaded around the space and when the target is identified by the RADAR, the information about the target like size, shape, speed and direction as a form of radio waves is received by the receiver.

iv. **Petals:**

The petals are made of thin aluminum alloy like Al-li due to its durability, resistance to heat, ductility, damage tolerance, low mass density and elasticity. Petals are made in a 3-Dimensional way, like squares are made concave and semicircles attached to them at bottom , so that each of the petals are hollow and the petals have a hole in the end where the claws are attached. At the end of the petals, claws are attached so that the claws get on and off as per the detection of the target. Each petal holds around 8 claws at the corner and it works accordingly. Electrostatic force is generated within the hollow space of the petal which is in the direction of the target. When the target comes at a certain distance, according to the formula of electrostatic force,

$$F = k\, Q1\, Q2/r^2$$

where F is the force, k is the Coulomb's constant, Q1 and Q2 are the charges and r is the distance between them.

The target is attracted towards the hollow space and the claws get off autonomously.

v. **PCB Board and Processors:**

Designing a printed circuit board (PCB board) to control all the access, the system uses a flex PCB due to its thermal stability, lightweight,versatility, durability and resistance to unpredictable radiations. These board uses memory like radiation-tolerant Magneto-resistive MRAM to capture and store the data of debris so that the information about the target are utilized properly. Moving on to the processors, they should work on with the response to RADAR and process the petals to produce electrostatic force autonomously when a target is identified by the RADAR. Processors should withstand radiation and harsh conditions of space, incorporated with multiple microprocessors. Microprocessors which are highly adaptable to space conditions like ERC32 are programmed to capture the RADAR receiver information thus helping in processing the petals to capture the target and hold it properly.

## 3. Properties:

This gripper is infused with certain properties to collect the target like the ability to capture the target, resistance to temperature, speed of the gripper and its autonomous properties.

i. **Ability of capturing the target:**

As the target is identified at a distance of about 800 to 1000 km, the distance and speed is also identified, the ability to capture the target when the target speed is at the rate of about 5 miles/s will be at a success rate of approximately 78% to 80%. The electrostatic force generated by the petals is more than the escape velocity of the target so that the rate of target escape is minimum and non-cooperative targets are also captured using this mechanism.It has an ability to capture the target ranging less than 10 cm.

ii. **Thermal stability:**

The main focus of this gripper is to withstand various temperature changes and be stable to extreme cold and hot conditions. The temperature range in LEO(low earth orbit) typically ranges from -65 ºC to +125 ºC and this may differ based on the orbit distance. The gripper should resist all temperature changes and work accordingly. The combination of kevlar, Al-li alloy and other components make the gripper resistant to various temperature conditions ranging about a range of -250ºC to +260 ºC for at least a month so that it can function in unpredictable temperatures of LEO.

iii. **Capture mechanisms:**

When a pulse from the transmitter hits the target, the beam is reflected to the receiver as radio waves and according to the waves generated, the information like speed, distance, size and direction of the target is determined.After the track of the object is found, it is then processed for orbit determination (OD) and Two Line Element (TLE) generation. Once the object is determined, by Van der Waals mechanism a weak electrostatic force is generated. The electrons of the respective petal move in a particular direction so that the protons of the target get attracted to the electrons.Once the target is attracted by the hollow petal, the claws get automatically closed, holding the material in the hollow space.

iv. **Statical analysis:**

The stress condition of each petal varies as the target of different mass, size, shape and speed are captured. The condition is not considered as each petal has its autonomous mechanism and working. So either an excess loaded petal or an empty petal, does not vary by its load but performs uniquely.The failure of one petal would not affect another one and continues performing autonomously.

## 4. Working:

As mentioned, the gripper works on with a static electrostatic force used to attract, capture and hold the debris and process accordingly.It generates a constant electrostatic force of specified amount to hold the debris without escaping from the gripper.

For example, given the escape velocity of an object in space with mass M is as follow,

$$vc = \sqrt{(2GM/r)}$$

where G is the gravitational constant, M is the mass of the target and r is the radius from the center of the Earth.

Calculating the force required to overcome escape velocity and hold the debris of mass M,

$$F= M/a$$

Assuming the average speed of debris as 10 km/s, therefore the force required will be,

$$F= M /10 \text{ N/s}$$

is the force required to attract debris beyond its escape velocity. Force comparison of different debris size is given in the TABLE I

| Debris radius ($\mu m$) | Low Earth Orbit Region 600 km altitude | |
|---|---|---|
| | $F_g$(N) | $Z_d$(e) |
| 0.01 | $1.2 \times 10^{-19}$ | 4.89 |
| 0.1 | $1.2 \times 10^{-16}$ | 48.9 |
| 1 | $1.2 \times 10^{-13}$ | $4.9 \times 10^{2}$ |
| 10 | $1.2 \times 10^{-10}$ | $4.9 \times 10^{3}$ |
| 100 | $1.2 \times 10^{-7}$ | $4.9 \times 10^{4}$ |
| 1000 | $1.2 \times 10^{-4}$ | $4.9 \times 10^{5}$ |

$F_g$ is the gravitational force of the particle in LEO and $Z_d$(e) is the total charge of the object in LEO.

Once the debris is captured by a petal, it generates an electrostatic force of

$$F=k\, Q1Q2/r^2 .$$

The stress of each petal is calculated to make it perform its intended function regardless of stress and mass and it is calculated by

$$\text{stress}= \text{force}/\text{area} ,$$

and are capable of holding debris of mass M with above conditions and when on holding the target after capturing will have speed as zero and doesn't require any force to hold the particle captured but this gripper constantly produces weak electrostatic force to hold them firmly from escape velocity.

Thus, after the petals are filled with debris particles, it is then enclosed with the claws to prevent them from escaping and produces the electrostatic force until the gripper is made defunct.

## 5. Safety and Risk Management:

Concentrating on the cause of failure, the main factor is resisting unpredictable harsh temperatures of Low Earth Orbit. To overcome the failures of thermal factors we used base layer as aluminum alloy and is coated with potassium silicate providing high resistance to sudden temperature variance. As there would be loss of power supply to the system which may result in failure of the entire system, lithium-ion batteries are connected with solar panels and the excess energy is stored to utilize for future purpose.As the system is made with 5 or 6 petals and each petal would function for the same purpose,when one petal fails to capture the target the other one would do the process, thus escape of the target is minimized. Since it has the ability to track the obstacles at a specified distance, the cause of crashing and failure is not a concern.

## 6. Conclusions:

This paper provides a basic overview of utilizing a floral shaped bio inspired gripper using electromagnetic waves for attraction and capture of debris in Low Earth Orbit. It mainly focuses on static and dynamic analysis of utilizing the design for space junk. It is designed in such a way that it consists of 5 petals working with an autonomous capture mechanism making it more productive and capturing large amounts of particles below 10 cm. The components utilized and processing of gripper are discussed in detail. Focusing on the static and dynamic analysis, resistivity to various temperature conditions and stress conditions are also discussed, especially concentrating on the components which should not contribute a debris once it's defunct.It would perform it's intended function at a success rate of 75% - 80% without causing failure or crash.

## References:

1. E.Stoll1, C.Trentlage, M.Becker.,The use of biologically inspired gecko material for active space debris removal of high priority objects (2024).

2. Prof. Abhijit Sen., Charging of space debris and their dynamical consequences (2016).

3. Abhishek Cauligi , Tony G. Chen , Srinivasan A. Suresh, Michael Dille , Ruben Garcia Ruiz2, Andres Mora Vargas, Marco Pavone , Mark R. Cutkosky.,Design and development of a gecko-adhesive gripper for the astrobee free-flying robot (2020).

4. Alaa Hassan , Mouhammad Abomoharam., Modeling and design optimization of a robot gripper mechanism (2017).

5. Minghe Shan, Jian Guo, Eberhard Gill.,Review and comparison of active space debris capturing and removal methods (2015).

6. Ethan W. Schaler, Donald Ruffatto, Paul Glick, Victor White;,Aaron Parness., An electrostatic gripper for flexible objects (2017).

7. Koki Tanaka, Matthew Spenko.,A gecko like/ electrostatic gripper for free flying perching robots (2020).