Analysis of grabbing space debris by software manipulator

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Abstract. Aiming at the problem that space debris is difficult to deal with, a software manipulator grabbing device is designed. The process of space debris grabbing by a software manipulator is analyzed, and the process of space debris grabbing is simulated based on the finite element method. The simulation results verify the rationality of space debris grabbing by the manipulator. To solve the small grasping range of the original manipulator, the structure of the manipulator was optimized, and its working process was simulated and analyzed.

1. Introduction
Space debris is useless human-made objects orbiting the earth. Their existence has brought huge hidden dangers to the aerospace industry. The number and sources of space debris are shown in figure 1. Space debris with a diameter of 1-10 cm in Leo accounts for 90% of the total number[1]. For the cleaning of space debris, there are currently three methods, such as collection, off-orbit disposal, and burning[2]. De-rail treatment refers to the speed at which the target has the binding ability to disengage from the centrifugal force of the original orbit after increasing the kinetic energy of the target. It then lowers the rotation to the ground, rubs against the atmosphere during the lowering, and burns or falls the target to the earth[3]. This method is only suitable for larger targets such as satellites that are out of service. Burning treatment means using a laser to irradiate the target, which will cause the prey to burn or disintegrate in space[4]. However, the outside air is too thin, the target cannot be entirely burned, and new fragments will be generated after the target disintegrates, causing secondary pollution. In contrast, the method of capturing space debris is more reliable. ESA proposed a geosynchronous orbit cleaning robot plan in 2002. They designed a 3-fingered manipulator to capture the obsolete satellite by targeting the solar wing root hinge of the obsolete satellite [5]. China launched a satellite targeting space debris in 2016. The satellite carries a three-finger under-actuated manipulator driven by a servo motor. By controlling the opening and closing of the three fingers, the pressure is generated to capture space debris. The manipulator’s capture range is 300 mm [6]. But space debris has a specific kinetic energy. It is difficult to capture with traditional rigid manipulators. If the grasping power is too large, the space debris will be disintegrated and cause secondary pollution; if the grasping force is too small, the space debris will not be grasped. Besides, the irregular shape and size of the space target increase the difficulty of capturing the space in orbit, which requires the robot to have good adaptability. Therefore, a soft manipulator has a natural advantage when capturing space debris[7].

Based on the current situation designed a soft mechanical device to capture space debris with a radius of 1-10 cm. Research the process of soft manipulator grasping moving objects, and analyze the grasping process of manipulator based on finite element analysis. Finally, the designed structure is optimized.
2. Mechanical structure design

The space debris capture device has a complete drive structure and execution end structure, which is fixed on the outside of the spacecraft through a base. The overall structure is shown in figure 2.

Figure 3 shows a schematic structure of the designed pneumatic robotic finger. The top of the pneumatic soft hand is called an expansion layer. It consists of uniformly spaced silicone rubber bulges with rectangular cavities machined in the interior and connected at the bottom. The bottom is usually a two-layer structure. The first layer is composed of a material with a larger elastic modulus than the deformation layer, used to restrain the downward deformation when the finger is deformed. The second layer is a strain layer, used to contact the grabbed object after deformation. It is usually made up of elastic material with relatively wear-resistant properties.

When a certain amount of gas is injected into the fingers during the driving process, the top body deforms , and the bottom limit layer cannot extend because it cannot twist. At this point, the finger bends from top to bottom due to the difference in the amount of phase change between top and bottom.

![Figure 2. The overall structure](image-url)

**Figure 1.** The number and sources of space debris

**Figure 2.** The overall structure
3. Analysis of the crawling process

3.1 Analysis of the crawling process

The grabbing process is divided into three steps. The first step is to change the spaceship into the target orbit after the target parameters are measured by the detection device in the spaceship; the second step is to drive the mechanical arm by internal air supply to approach the target so that the manipulator reaches the target position; the third step is to input the gas from the air source controlled by solenoid valve into the mechanical hand so that the mechanical hand can bend and contact the target object, then exchange energy with the space debris to eliminate it. It consumes the kinetic energy generated by the spinning motion of space debris. Continue to increase the air volume. Fingers are squeezed against the target to create positive pressure, relying on the friction of positive pressure to complete the grab.

The Finite element model of the grabbing process is established by using simulation software ABAQUS[8].

- The object in the simulation model is space debris with a diameter of 10 cm.
- The Ball instead of space debris in the simulation model.
- Because the ball and three-fingered robot hand are symmetrically distributed at 120 degrees, to reduce the amount of calculation, a single finger is taken to contact the ball in the simulation model for contact analysis.
- The robot is approaching the target at a plodding speed with only the spin speed of the ball.

Establish a three-dimensional model of single-finger robot finger and ball and import into ABAQUS; the Expansion layer and strain layer are specified as hyperelastic material silicone rubber, and the defined parameters are 0.08, 0.016 using Yeoh constitutive model[9]. Define the limiting layer as an elastic material with an elastic modulus of 60Gpa and a Poisson ratio of 0.02; define the sphere as homogeneous and the density as 7.85g/cm3 rigid material; meshing; replacing pressure input by exerting pressure on the inner surface of the chamber; restricting the fixed end of the manipulator by boundary conditions. restricting its six degrees of freedom by fully fixing it; giving the ball a certain amount of kinetic energy; In the process of output, the deformation nephogram and overall energy change nephogram are shown in figure 5. It can be seen from the cloud picture that the contact point of the soft finger and the small ball will have the maximum displacement after grasping, which is due to the positive pressure generated between the soft finger deformation and the ball, and then the friction force is generated, and the ball is constrained by the friction force.
3.2 Analysis of simulation results

The energy change of a unit on the finger during the grasping process is selected, as shown in figure 5. From figure 5, it can be seen that the kinetic energy of the unit chosen gradually increases during the grabbing process due to the energy interaction between the manipulator and the space debris at the beginning of contact with the space debris. The kinetic energy of the space debris decreases and becomes the kinetic and elastic potential energy of the manipulator. The kinetic energy of the unit is reduced to zero. The elastic potential power of the company consumes a small part of the kinetic energy of the ball, indicating that the grab is complete.

The overall energy transformation in the grasping process is shown in figure 6. It can also be seen from figure 6 that the fluctuation of the overall kinetic energy indicates that the chamber pressure of the manipulator works to offset the kinetic energy of the ball during the grabbing process. Since the manipulator is a soft material, it will bounce off repeatedly during the grabbing process, so it fluctuates until the end of grabbing. The gradual decrease of the overall elastic strain energy also indicates that the grabbing process is underway, and the reduction to zero marks the completion of holding.
4. Optimization of mechanical structure
In the second chapter, the gripping angle of the three-fingered robot is determined by the installation distance. It can only grasp the objects within the distance between the three fingers. The structure is optimized in this paper, and the optimized structure is shown in figure 7.

The optimized three-fingered gripper can grasp a broader range of targets. When the target diameter is within the distance between three fingers, it can be held directly; When the target diameter is larger than the distance between the three fingers, the opposite air cavity on the contact side of the target is inflated to make the mechanical finger bend in the opposite direction to expand the grasping diameter. When the finger wraps the target, the ventilation of the opposite side is discharged, and the manipulator is ventilated on the grasping side to make the manipulator bend towards the target object to complete the grasping. Based on the finite element analysis, the deformation of the improved three-finger robot is shown in figure 8.
5. Conclusion
The simulation analysis on space debris capture by the robot hand shows that the soft robot hand can grasp space debris with a certain kinetic energy well. Aiming at the problem of a small grasping range of robot hand, the optimized structure is given and the optimized structure is simulated and analyzed. The result shows that the grasping angle is improved.

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