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Plisetska E.I. student of speciality 134 Aviation and rocket and space engineering*(National technical university of Ukraine "Igor Sikorsky Kyiv polytechnic institute", Kyiv, Ukraine)***ENGINEERING SOLUTIONS FOR THE DEVELOPMENT OF SATELLITES WITH SPACE DEBRIS DISPOSAL FUNCTIONS**

Space debris contamination has become a critical threat to the safety of modern satellites and future missions. As the number of spacecraft in orbit and collisions between objects grows, more and more fragments appear that can cause new collisions, creating a cascading effect that impairs the normal functioning of orbital objects. Modern engineering solutions are aimed at developing satellites with space debris disposal capabilities, such as autonomous manoeuvring technologies, non-contact orbit reduction systems, methods for capturing unstable objects, and integrated reusable platforms.

Various methods effectively capture space debris, including large and unmanageable objects. One of the critical approaches is using robotic manipulators that allow precise interaction with the target due to the high-precision control and adaptability of the systems. Such manipulators can ensure safe gripping even in the presence of rotation or instability of the object, as they can stabilise the load and compensate for external disturbances. Special attention is paid to adaptive control in the design of these devices, which allows instant response to changes in the trajectory of the object using the methods of integral sliding mode and delay control. This ensures high stability and accuracy despite uncertainties and unpredictable external influences on the manipulator and the target object [1].

Another promising approach to capturing space debris is using flexible tethers, such as nets, harpoons, and cables, allowing capture without rigid mechanical contact. For example, mesh capture stabilises rotating objects by covering them from all sides, reducing the risk of mesh destruction and entanglement. Flexible connections also ensure safe transportation of debris after capture. Despite the complications arising from an engineering point of view, this approach can be applied in practice for repeated debris removal missions because it does not require preliminary preparation of an object for capture and allows working with objects of different shapes and sizes [2,3].

New technologies have been proposed using geomagnetic energy (GME) as a source for manoeuvring space debris in low orbits. This method makes it possible to change the orbit of objects without fuel, using the torque reserve created by the interaction of the Earth's magnetic field with the satellite's electromagnetic field. Gradual acceleration is achieved through prolonged exposure to magnetic torque, which reduces the need for conventional fuels or large thrusters. This approach significantly reduces the cost of missions where mass and space savings are critical and allows the objects to be disposed of within a few days without additional collision risks [4].

Micro- and nano-satellite systems with high manoeuvrability are also a promising technology for removing small debris. They consist of compact satellites operating in synchronised groups and performing complex manoeuvres in orbit. These satellites can identify and capture objects in real time thanks to the modular sensor and capture systems. High navigation accuracy allows them to work with small objects, critical for disposing of debris fragments up to several centimetres. These satellites can operate autonomously or coordinate with larger platforms, increasing mission efficiency [5].

Among the latest engineering solutions are universal space debris removal platforms that combine several capture and deorbitation methods, such as harpoon, net and robotic manipulators, allowing for handling objects of various sizes and shapes. Each technology is

used at the appropriate stage: the harpoon provides initial capture, the net stabilises the object, and the manipulators fix it for further transport or de-orbiting. Such platforms are equipped with solutions for controlling rotational motion and braking, which helps to avoid uncontrolled collisions and minimise the generation of additional debris. Integration of control algorithms and optimisation of structures ensure stability when holding the object, reducing the risk of fragmentation during transport [3].

Modelling and experimental testing methods are essential in developing engineering solutions to combat space pollution and improve space debris capture technologies. Ground-based tests allow the stumbling of large objects by assessing their behaviour during rotational stabilisation before capture, which helps to optimise capture systems while minimising the risk of uncontrolled movements during transport. Impact pressure detection methods are additionally used to help predict loads and improve the design of gripper mechanisms adapted to space conditions to control the distribution of dynamic loads at the contact points. The above technologies reduce the likelihood of damage and the formation of additional debris fragments [6].

Prospects for the development of space debris removal systems include the introduction of adaptive control algorithms that can learn in real-time to predict the movement of unstable objects and quickly adjust satellite trajectories. The possibility of integrating autonomous diagnostic modules that allow satellites to automatically assess the condition of grippers and respond quickly to potential failures is being considered, which helps prevent the formation of additional debris fragments. In addition, it is planned to use distributed sensor networks to jointly track debris trajectories in real-time, which will allow simultaneous monitoring of several objects in orbit and increase the efficiency of debris collection operations [5].

References:

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