Durham University
Space Research Centre

Capturing Spent Rocket Bodies with Robots

Dr Nikos Mavrakis

Space debris is a significant challenge to the continued use of space for the benefit of humanity. Space debris removal is core to advancing space sustainability, and rocket bodies are a significant identifiable target for removal efforts.

What are rocket bodies?

- Rockets are the main mode of launching satellites into space.
- Rockets consist of multiple stages, many of which are left in orbit once their fuel is used up.
- The upper stage ("kick stage") of a rocket places the satellite in its final orbit. The kick stage then stays in space. Often, its deorbiting time can vary from days to decades, or even longer.
- Rocket bodies constitute around 11% of all space debris objects larger than 10cm in diameter.

What are the dangers of spent rocket bodies in orbit?

- Their size can vary. Smaller rocket bodies can be less than a metre, while larger ones can be more than 10 metres long
- The mass of an empty rocket body can range from a couple of kilograms to multiple tonnes
- The tanks of rocket bodies are pressurised, which increases the possibility of in-orbit explosions
- Rocket bodies breaking up have the potential to create more pieces of dangerous debris
- Rocket bodies have been designated as the most dangerous objects in Low Earth Orbit (LEO). Out of the top 50 most concerning objects in LEO, 35 are spent rocket stages.

What are the challenges of deorbiting rocket bodies?

- Rockets do not have mechanical docking or capturing points.
- Due to fuel leaks and lack of orientation control systems, rockets are tumbling uncontrollably, making physical contact with them challenging.
- Their pressurised tanks require more delicate capturing methods where soft contact is needed. This contrasts with many proposed and demonstrated space debris capturing methods, such as harpoons, capturing nets, and engulfing mechanisms.
- Soot and other burned propellant residue may remain in the nozzle cone of rocket bodies. If disturbed, this residue may detach and create more millimetre-sized debris objects, which are dangerous and harder to track.
- There is scarcity of available visual data of spent rockets in orbit. The material composition of the rockets can be unknown, as many were manufactured by space agencies and companies that no longer exist with limited documentation.

Robotics as an enabling technology for rocket body capturing

- Robots can be a crucial technology to develop for reliable capturing and deorbiting spent rocket bodies.
- Robots are capable of soft contact that minimises disturbance on the rocket body surface.

Durham University
Space Research Centre

- Robotic vision and AI are crucial for estimating the state, composition, tumbling rate, and mass of the rocket, as well as identifying potential grasping points and contact surfaces for the robot.
- Robotic contact methods can vary, from grapples and robotic fingers to adhesive contact pads and soft mechanisms.
- Robots are straightforward to simulate and test in testbeds, with extensive research heritage to influence their design.

Recommendations for UK Government

In addition to technical support, we recommend activities should be supported through law and policy in the UK. Developing law and policy frameworks to guide these activities would be a significant step towards realising the goals of the UN's Long Term Sustainability Guidelines and the King's Astra Carta initiative.

1. Include a UK-registered spent rocket stage as a deorbiting target for future UKSA Active Debris Removal missions and tenders.
2. Invest in the development of underpinning testing and verification technologies for space-based robotic capturing, such as advanced simulation capabilities and hardware testbeds for Active Debris Removal.
3. Further invest in the development of space debris tracking technologies and develop a risk catalogue of rocket bodies, evaluating the probability and severity of fragmentation.
4. Work with academia, industry, and ESA to develop protocols and standards to de-risk space operations for approaching, capturing, and deorbiting uncooperative rocket bodies.
5. Continue law and policy development around sustainability and incorporate protections and incentives for debris removal in these frameworks.

What is SPARC doing?

Robotic dexterity is one of the most important capabilities for robots. Today on Earth robots can handle objects of variable shapes and masses and perform delicate manipulations with them. Autonomous robotic grasping is a fundamental capability needed to achieve robotic dexterity, particularly in space. Robots need to identify suitable grasping points on an object and evaluate whether the grasp will be secure during handling.

Space robots presently lack dexterity compared to their terrestrial counterparts. SPARC is working towards developing methods for autonomous robotic grasping in microgravity. We study the fundamentals of achieving contact stability in microgravity conditions, and develop novel algorithms for synthesising docking points on uncontrolled and unknown targets, with applications in space debris removal, in-orbit servicing, and manufacturing on lunar surface.

SPARC is developing not only new technical tools for monitoring space activities, but also the research base for understanding the political and legal dimensions of satellite manoeuvres and space security.

More information:

durham.ac.uk/space-centre

sparc@durham.ac.uk