Survey of Landing Methods on Small Bodies: Benefits of Robotics Manipulators to the Field

P. Peñarroya[1], S. Vyas[2], R. Paoli[3], and K. M. Kajak[4]

[1]Deimos Space SLU, Spain, Pelayo.Penarroya@deimos-space.com
[2]German Research Centre for Artificial Intelligence & University of Bremen, Germany, Shubham.Vyas@dfki.de
[3]Universitatea „Alexandru Ioan Cuza" din Iași, Romania, Roberto.Paoli@uaic.ro,
[4]German Aerospace Center (DLR), Germany, Karl.Kajak@dlr.de.
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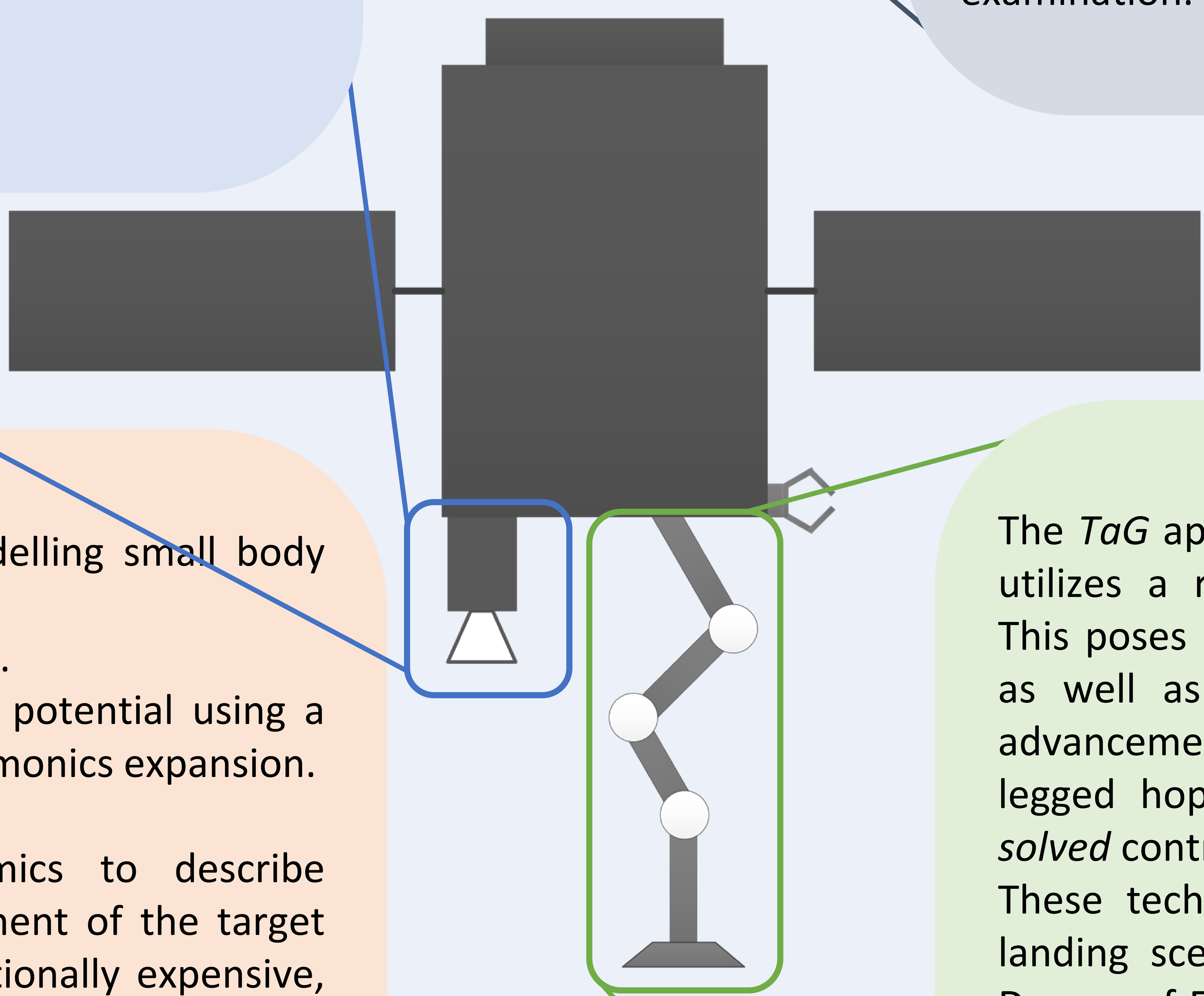
Perception System

Utilizing the full potential of a robotic arm based surface hopper/lander will require beyond-state-of-the-art sensing and autonomy for surface navigation. The system will have to be aware of surface topography, avoid obstacles, and step onto firm ground.
The visual navigation concepts shown in NEAR Shoemaker, Hayabusa, Rosetta, OSIRIS-Rex are not enough for this task. Humans were responsible for selecting landmarks to track during navigation tasks of these missions. However, this process should become autonomous for all asteroid landing missions.
Based on this perspective, we are developing a navigation system for a generic landing zone based on neural networks.

GNC

Landing on a minor celestial body, whose characteristics and environment are mostly unknown by the time of arrival, poses one of the main challenges in space exploration. Missions like OSIRIS-Rex or the Hayabusa series opted for a safer *Touch-and-Go (TaG)* approach, where the contact is only momentaneous, shortening the sampling capabilities of the mission. Others, as the Rosetta mission, preferred to deploy a small lander that was supposed to anchor itself onto the surface to achieve its science targets.
Using robotics to relax the mission constraints for the landing segment is proposed to ease the trade-off between risk and returned value. The integration of a robotic arm into an autonomous GNC system could lead to new possibilities such as increasing mission robustness or enabling new mission segments like surface hopping or deeper terrain examination.



Small Body Dynamics

The following approaches for modelling small body dynamics are promising:

- Trivial point mass approximation.
- Description of the gravitational potential using a truncated external spherical harmonics expansion.
- Polyhedron dynamics.

We can use polyhedron dynamics to describe accurately the dynamical environment of the target body, but the method is computationally expensive, making it unsuitable for an autonomous on-board GNC system. This approach could possibly be made computationally efficient using modified formulas from polyhedron dynamics.
Another approach consists of computing the external spherical harmonics coefficients directly from the shape model.
Furthermore, the possibility of using internal harmonics to describe the dynamics inside the smallest sphere circumscribing the target body is currently being investigated.

Robotic Manipulation

The *TaG* approach used by previous missions for landing utilizes a relatively simple spring-damper mechanism. This poses limitations on both the landing requirements as well as the sample collection capabilities. Recent advancements in humanoid robotics have enabled single-legged hopping and balancing to be considered as a *solved* control problem.
These techniques could be applied to the small-body landing scenarios to increase landing robustness. High Degree of Freedom *(DoF)* manipulator makes the system gainfully robust as a whole as the failure of single joint converts it to a lower *DoF* manipulator which can still provide adequate control.
Post-landing, sample collection can be enhanced by using traditional robotic *pick-and-place* and changeable tools. Furthermore, having a robotic manipulator also allows zero-propellant exploration and high-fidelity gravity field modelling using hopping manoeuvres.