Enhanced Vision-Based Algorithms about Small Bodies: Lessons learned from the Stardust-R experience

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Abstract. In this work, the author collects lessons learned and future challenges identified in the field of enhanced vision-based navigation algorithms. These points are collected after 3 years of research experience within the H2020 Stardust-R network and pose points of discussion for future trends within the space community.

Keywords: Small Bodies · Navigation · Image Processing · Artificial Intelligence .

Introduction

Data-driven Image Processing (IP) algorithms represents an accurate, robust, generalized alternative to traditional IP for vision-based applications about small bodies. They can either be used for navigation applications such as in [1] or for IP tasks that enables on-board autonomous capabilities [2].

Their use has spilled from traditional Earth-related computer vision applications (automotive, drones, intelligent systems, etc.) to space-related applications. Space, however, has specific environmental conditions that are not shared among other domains and pose new and unforeseen challenges that need to be properly addressed.

Challenges

During these years, several challenges have been identified that can impact the development and application of data-driven IP algorithms in real-case scenarios.

The lack of publicly available labeled datasets (both synthetic and from real missions) is perhaps the most demanding one. In their absence, the algorithm designer has two choices: either to generate one on its own or to use unsupervised algorithms for the task. In the former case, it requires interdisciplinary skills that cover also aspects related to the rendering within an artificial environment. In the latter, it largely reduces the design space of the algorithms. Moreover, the design of a dataset generator is not a simple task and generally requires a non-negligible effort. If performed by the same individual, it means that the algorithm

designer is forced to shift a large portion of the effort to data generation and preparation, limiting the energy usually solely focused on algorithm design. An official and validated open-source rendering software for space applications does not currently exist. Since their design requires considerable effort, they are often not publicly available, as their sole possession poses a strategic advantage both for industrial and research applications. This same reasoning applies to datasets, which are usually jealously kept

Is very rare and complex to develop full end-to-end pipelines that simultaneously cover image generation, IP algorithm design, filtering, and hardware-in-the-loop testing. Often it is simpler to focus only on a portion of such pipeline, which rises risks for functioning fully integrated systems for real-world applications. Moreover, algorithms are often not assessed with real images. Robustness to noise or other real-world effects is not always taken into account, posing serious concerns in terms of robustness.

Hardware limitations are often not considered during the design phase. This is especially critical when considering complex network architectures that involve a large number of operations, often performed in parallel using modern GPUs on day-to-day working stations or servers. Distinction shall be made between training and inference, but often in both cases, algorithms are tested using available hardware typical of modern working stations rather than representative space-qualified hardware. The latter however is notoriously lagging behind in terms of computational power when compared to modern day-to-day hardware.

Lastly, as the cost of specialized hardware for training and testing these algorithms is rising quickly (GPUs, TPUs, and hardware accelerators), there is a tangible risk that smaller research centers will be left behind in terms of access to such enabling technologies. This poses a major risk for the development of data-driven, architecture-based methods which require substantial computational effort for training. This phenomenon could also potentially impact hardware-specific design or requires interdisciplinary skills outside the classical aerospace community. Attracting talents with the necessary skills from other booming sectors could result in increasingly more difficult, causing the space community to catch up against other sectors that can receive funding more easily.

References

1. Pugliatti M., Franzese V., Topputo F., : Data-driven Image Processing for Onboard Optical Navigation Around a Binary Asteroid. Journal of Spacecraft and Rockets **59**(3), 943–959 (2021)
2. Pugliatti M., Topputo F., : Small-Body Segmentation Based on Morphological Features with a U-Shaped Network Architecture. Journal of Spacecraft and Rockets **XX**(XX), 1–15 (2022)