Real-time image rendering for simulation of thermal infrared cameras with application in Space Debris Removal

Martin, Iain; Dunstan, Martin; Vural, Deren; Sanchez-Gestido, Manuel

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

Link to publication in Discovery Research Portal

Citation for published version (APA):
Martin, I., Dunstan, M., Vural, D., & Sanchez-Gestido, M. (2021). *Real-time image rendering for simulation of thermal infrared cameras with application in Space Debris Removal*. Paper presented at ESA Clean Space Industrial Days 2021.

ESA CLEAN SPACE INDUSTRY DAYS 2021

Iain Martin, Martin Dunstan, Deren Vural
University of Dundee, Dundee, DD1 4HN, United Kingdom, imartin@.dundee.ac.uk

Manuel Sanchez Gestido, ESTEC, ESA, Noordwijk, The Netherlands, manuel.sanchez.gestido@esa.int

Real-time image rendering for simulation of thermal infrared cameras with application in Space Debris Removal

Abstract

Space Debris Removal applications will require precise navigation and orbital manoeuvres so may include a variety of onboard sensors to support different types of autonomous guidance systems. Vision and LiDAR-based Guidance Navigation and Control (GNC) systems are well-established for space applications including planetary landers, small-body approach and landing, hazard detection for precise landing, orbital cannister capture and spacecraft docking manoeuvres. Cameras that sense radiation in the infrared frequency ranges, are now a viable additional sensor that can be considered for use in future space applications because they can provide additional information to vision-based systems and could be particularly useful for autonomous GNC in space debris capture missions.

Autonomous GNC systems require extensive testing with realistic images. Modern artificial intelligence systems, based on machine-learning algorithms, require extensive data sets for training, testing and validation. Software test platforms that can provide sufficiently realistic simulated sensor data have been shown to be useful for testing, developing and benchmarking GNC algorithms for training testing systems in real-time [1], but currently focus on simulating vision and LiDAR-based sensors. There are also well-established and validated thermal simulation tools (e.g., ESATAN [2]) that model heat transfer and thermal profiles of orbiting spacecraft to enable thermal engineers to manage the thermal control of spacecraft. These thermal solvers work on simplified geometric models to simulate heat flow but current limitations on model resolution and analysis processing time make them unsuitable for generating realistic thermal emission images at the resolution of thermal sensors in real-time.

PANGU (Planet and Asteroid Natural Scene Generation Utility) is a long-established, validated software package for generating realistic simulated images of onboard vision and LiDAR sensors of high-resolution planetary surfaces, asteroids, surface rovers and spacecraft, all in real-time at framerates expected of navigation cameras in a variety of tests systems such as off-line, open loop, closed-loop and hardware-in-the-loop type tests [3]. PANGU includes support for surface and spacecraft modelling, a custom high-speed renderer that can handle very large model files, CAD file import and export and an integrated GPU-based real-time camera module. Recent PANGU development has focused on designing and implementing functionality to generate representative, simulated thermal images of high-resolution models in near real-time for simulating planetary surfaces, orbiting spacecraft and other objects which could include space debris, and a stateless, equation-based approach for spacecraft.

We use a stateless thermal model based on thermal equilibrium equations [4] to generate representative thermal images from polygon models in real-time, applying the equation-based model at the pixel level which allows us to generate high-resolution images of complex geometrical models in near real-time (i.e. >=10Hz). The equation-based model sums the different thermal contributions and has been designed to be extendable in future enhancements. The individual sources currently included in our model are:

- background heat from space or a laboratory,
- direct solar considering cosine foreshortening, and dynamic shadows,
- reflected solar from a neighbouring planet or large Moon,
- emission from a neighbouring planet or moon,
- internal heat absorption and dissipation, and
- internal heat sources.

PANGU uses these thermal contributions to calculate temperatures at the pixel level and can generate both false-colour temperature images and thermal radiance images, using Planck’s law to convert temperatures to radiance image pixel intensities. There is currently a limited set of real thermal images of orbiting spacecraft, so the equation-based spacecraft thermal model has initially been evaluated by comparing the temperate ranges obtained to low-resolution equivalent simulations run on a validated heat-transfer analysis tool, running finite-difference and finite-element analysis in equivalent orbital scenarios.

We will present the equation-based thermal simulation model, show the validation images and temperature comparisons where we compare simplified PANGU models with equivalent ESATAN simulations to validate the temperature calculations, and show equation-based thermal images of asteroid Ryugu and the International Space Station where we can compare our simulated images with real thermal camera images.

References

[1] M. Dunstan and K. Hornbostel, “Image processing chip for relative navigation for lunar landing”, in 9th International ESA Conference on Guidance, Navigation, and Control Systems (GNC 2014), 2014.
[2] ESATAN, https://www.esatan-tms.com/.
[3] I. Martin, S. Parkes, M. Dunstan, M. Sanchez Gestido, G. Ortega, “Simulating planetary approach and landing to test and verify autonomous navigation and guidance systems”, ESA GNC 2017, Salzburg, May 29th–June 2nd, 2017.
[4] C. J. Savage, “Spacecraft Systems Engineering (3rd Ed)”, chapter 11 “Thermal control of spacecraft”, Wiley.

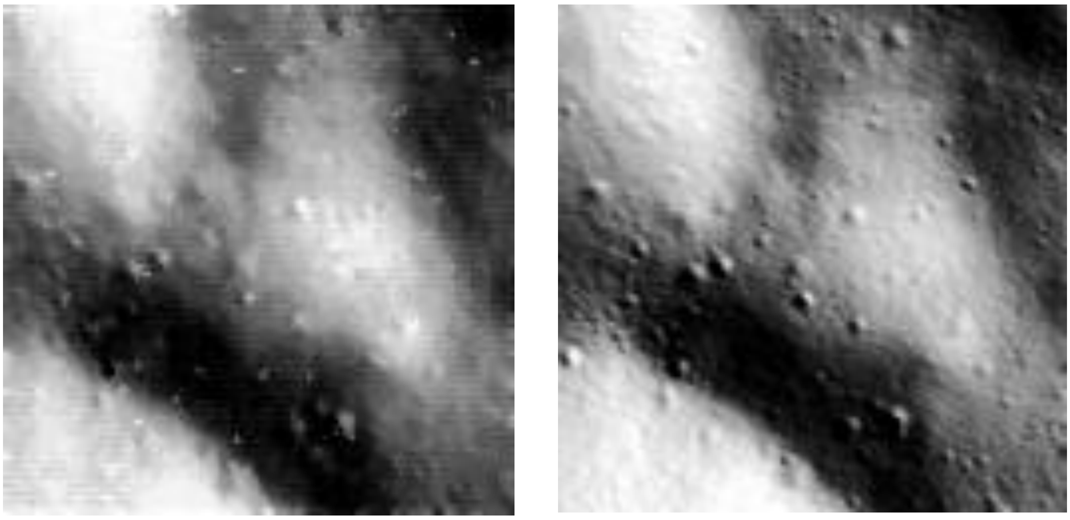

Figure 1: Clementine image LLA1112D.032 ((left) and the PANGU simulated equivalent (right)

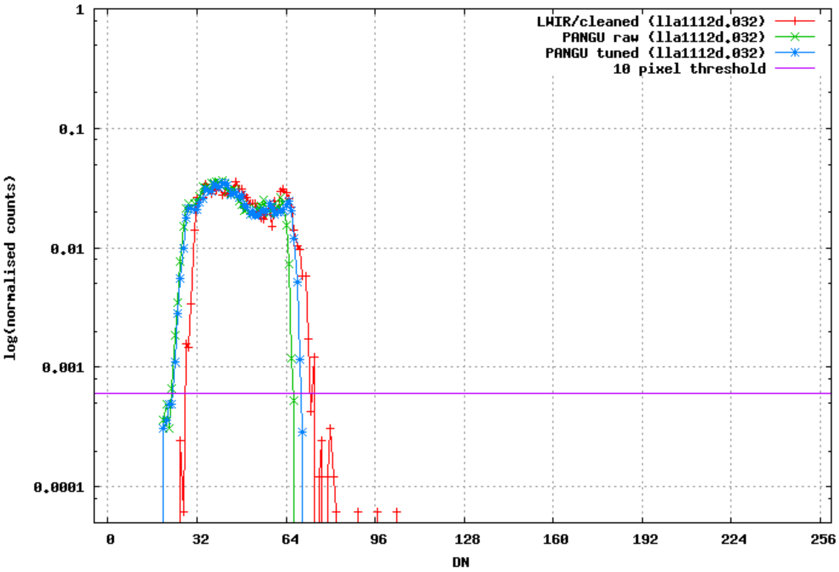

Figure 2: Grey-level histogram plots of Clementine image LLA1112D.032 (left) and the PANGU simulated equivalent (right)

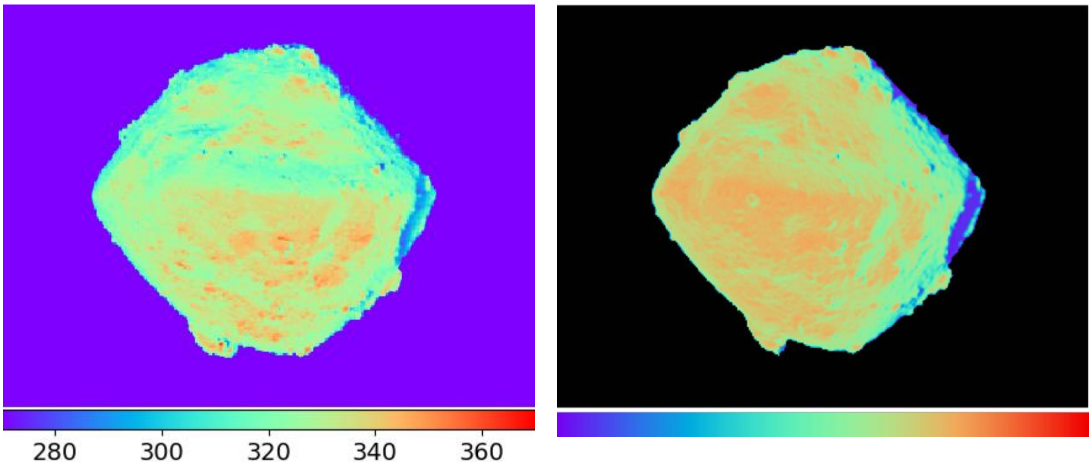

Figure 2: Hayabusa2 temperature image (left) and the PANGU simulated equivalent (right)