STAR-Dundee

SpaceWire and SpaceFibre Expertise

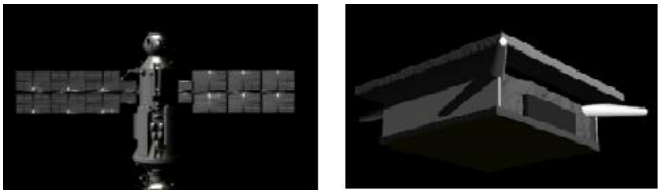
PANGU - Planet and Asteroid Natural scene Generation Utility

Overview

PANGU v6 is a powerful toolset for modelling and generating high resolution images of surfaces of planetary bodies such as Mars, the Moon, Mercury and asteroids, as well as spacecraft and surface rovers. It uses both real and synthetic data to simulate camera and LiDAR images to test vision-guided planetary navigation, guidance and landing systems. Images can be rendered in visual and thermal infrared bands with a full camera model implemented on GPUs for fast rendering.

PANGU images of the Moon (left), Earth orbit (centre) and Mars (right)

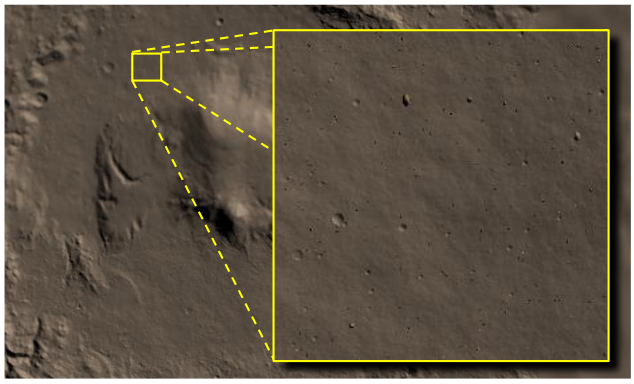
Developed by the University of Dundee, with support from the European Space Agency (ESA), PANGU v6 offers a high degree of realism while operating at near real-time speeds on 64-bit Windows and Linux PCs that support OpenGL and GPU shaders.



Example PANGU thermal images: an ISS Section (left) and PRISMA/Tango mock-up (right)

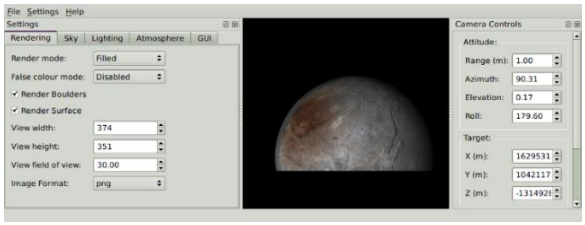
PANGU can render high-resolution images to simulate visual camera sensors but can also simulate thermal infrared sensors, rendering both thermal radiance and temperature false colour images.

Surface modelling



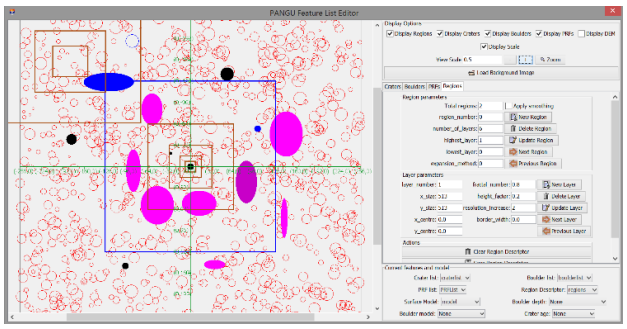
PANGU Gale Crater/MSL landing site showing resolution range

PANGU can generate multi-resolution models, starting from real or synthetic shape models and Digital Elevation Models (DEMs) which cover all, or part, of a planet, moon or asteroid. Common DEM projections and sample formats are supported along with the ICQ format for asteroid shape models. The ability to create very large models (*e.g.* greater than 64GB) enables missions to be simulated to a high degree of realism, with the terrain resolution varying from kilometres at the start, to centimetres at the target landing site.



PANGU renderer GUI with settings and control panels

The initial (base) DEM can be obtained from instruments such as NASA's Lunar Reconnaissance Orbiter (LRO) Laser Altimeter (LOLA) or ESA's High Resolution Stereo Camera (HRSC). Alternatively, a DEM can be created by PANGU using fractal techniques with user-defined roughness. Base DEMs can be enhanced to higher resolutions using interpolation with generated fractal detail.



PANGU surface modeller GUI feature editor window

Realistic craters can be added using statistical models of properties such as age/diameter distribution. Aging factors ensure that the resulting craters match those observed in images of real terrain. Boulders and positive relief features can be added to the surface, controlled by various statistical distributions. For models of Mars, barchan dune fields can be modelled and the craters can have flat bottoms, as if filled by dust. Albedo/colour maps can be applied for extra realism on both planetary and asteroid surfaces. The Hapke reflectance function can be used to model the properties of planetary surfaces.

PANGU image of Itokawa with spacecraft shadow and Hapke effect

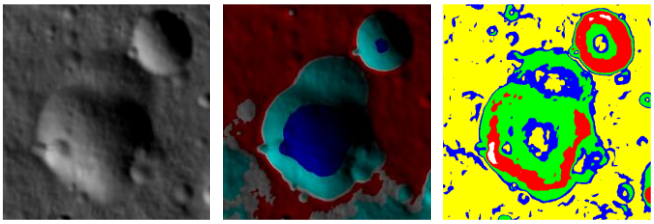
Sensor simulation

PANGU can be used to generate camera and LiDAR images in open or closed-loop simulations of the full descent of a planetary lander from orbit to ground, surface roving, and in-orbit operations such as rendezvous. A single scattering atmosphere model can be used for simulations involving the Earth, Mars or even Titan. Integration with the NAIF/SPICE system allows images to be generated using publicly

available historic and predicted data for spacecraft and planetary bodies at times of interest. The sky can be rendered using a uniform colour; stars from a catalogue can be rendered in colour with a user-defined point spread function.

PANGU Itokawa model (l), with synthetic albedo (c) and AMICA image (r)

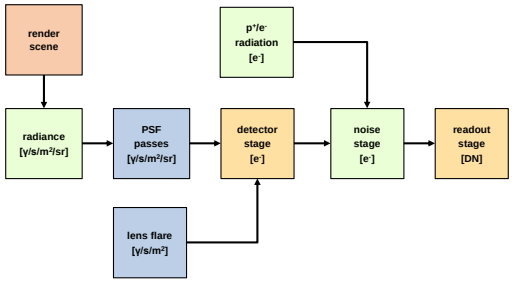
Open-loop simulations use a script file to control time, the camera and movable objects. Closed-loop simulations use the TCP/IP interface which is accessible from C/C++, Java, MATLAB and Simulink. Visual, LiDAR and RADAR data can be acquired along with the results of terrain look-ups, line of sight and other queries.



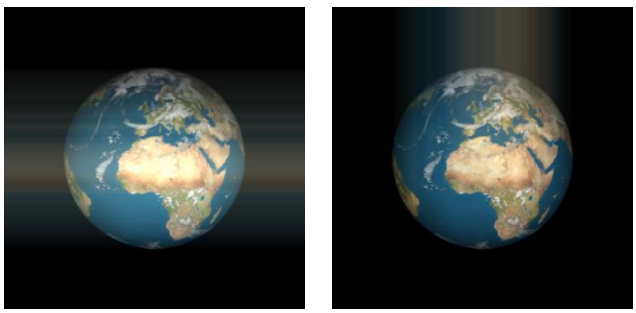
PANGU visual (left), height map (middle) and slope map (right) images

Camera model

A sophisticated physics-based GPU camera model includes photon shot noise, quantum efficiency, thermal dark current, read-out noise, radiation events, photo-response non-uniformity, radial optical distortion, tangential distortion, smear, communication errors, contrast abnormalities and multiple-weighted Gaussian PSF to model scattered light. Pixel values can be represented in floating point or digitised with up to 16-bits of precision to match real sensor ADCs. The radiance images that are input to the camera model can be at very high resolutions such as 4096×4096 (or larger). The effects of CMOS "rolling shutter" can be simulated as well.



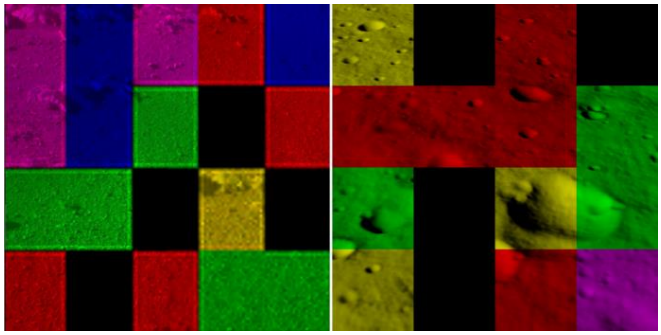
Data flow diagram of the PANGU physics-based camera model



Readout/reset smear in a PANGU image of the Earth

Reflection models

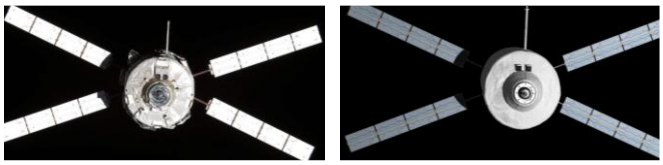
Lighting and shadowing are vital components of any system that generates realistic images of planetary surfaces. PANGU allows surfaces and boulders to be rendered with different reflection models to simulate different material properties. The standard Lambertian diffuse reflection model is included as well as Hapke, Oren-Nayar, Blinn-Phong and Cook-Torrance BRDFs.



Communications errors: PIA23248 (left), PANGU representative (right)

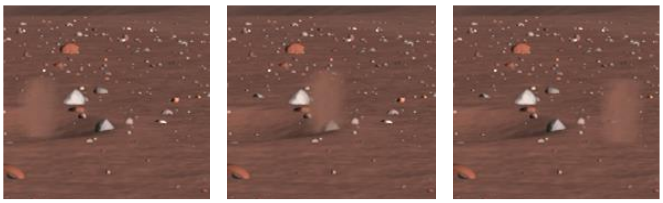
Shadow casting

Off-line shadow maps can be used for simulations where the Sun and other objects are static and where penumbra is an important consideration; dynamic shadow maps can be used in other situations where the Sun and/or other objects move more rapidly. The GPU-based single-scattering atmosphere model implements both Rayleigh (gas) and Mie (aerosol/dust) scattering.



Real (left) and PANGU (right) images of ESA's ATV spacecraft

CAD models of spacecraft can be imported into PANGU and then enhanced to add properties such as metal surfaces, OSR tiles, solar panels and MLI. Models can include joints to allow booms to be extended, wheels to turn and solar panels to unfurl and track the Sun. For Martian scenes movable dust devils can be included, which can be rendered from both rover and lander cameras. The dust cloud lifted by landing thrusters can be modelled as well.



PANGU image sequence showing a moving dust devil on Mars

PANGU images of stars in Orion with different point spreading functions

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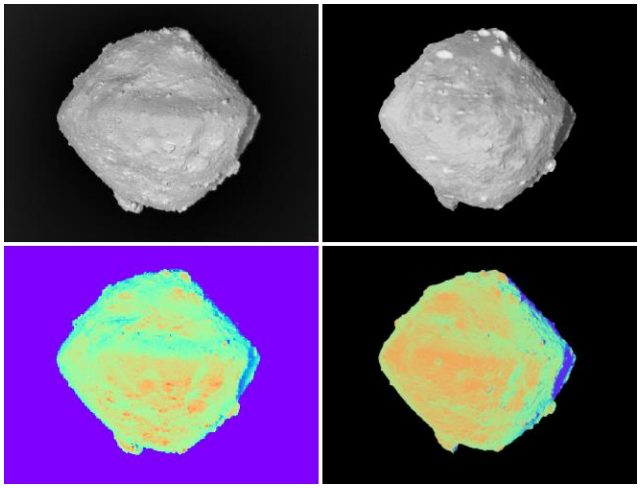
Thermal simulations

PANGU v6 includes a lookup table-based thermal image rendering model using a diurnal temperature profile for the Moon and similar planetary surfaces or asteroids with modifications for seasons in the polar regions, thermal lag on fast rotating bodies, shadowing, solar distance, surface material effective absorptivity, thermal inertia of the surface, and local variations in emissivity and absorptivity.



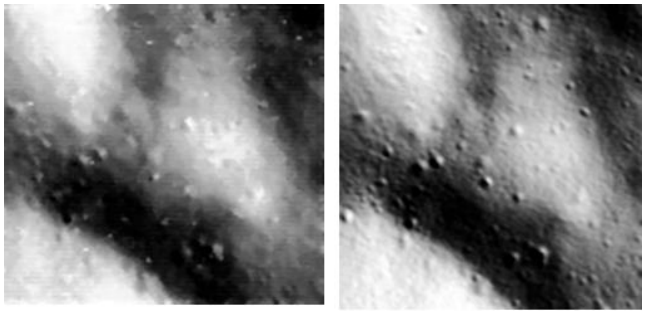
Hayabusa2/TIR images of Ryugu (left) and PANGU simulation (right)

For scenarios involving spacecraft models, a zero-capacitance, equation-based, thermal rendering model has been developed to include thermal energy from solar, planetary reflectance, planetary emission, background radiation, and internal heat sources.

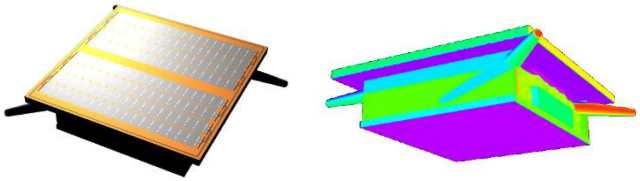
PANGU thermal radiance image of part of the International Space Station

Validation

PANGU has been extensively validated through a combination of image comparisons with real images and review from expert planetary scientists. Specific PANGU features are validated by generating PANGU simulations of real images and comparing the results though visual comparisons, image statistics and by applying representative image processing algorithms on both the real and synthetic images of the same surface or object, to validate that the PANGU images are representative of the real scenario.



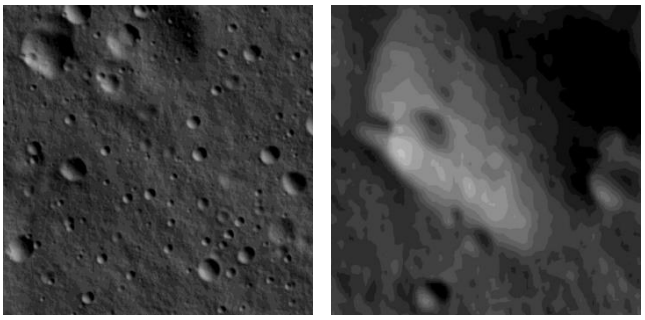
Cleaned Clementine/LWIR image LLA1112D (left) and from PANGU (right)



PANGU PRISMA/Tango model (left) and false colour temperature (right)

Import/Export

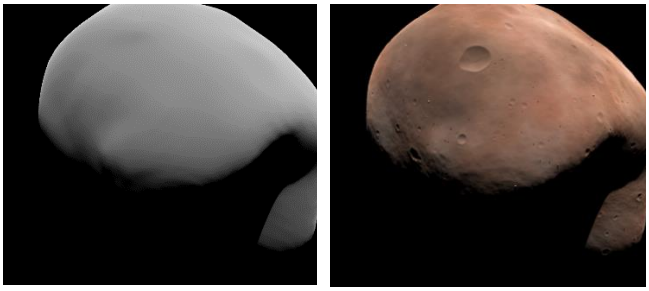
PANGU can import/export planetary DEMs in PDS format, asteroid shape models in ICQ or OBJ format, and CAD models in various popular formats. PANGU v6 can also generate MP4 videos, either from a sequence of generated images, or directly when running the simulation (requires FFmpeg or equivalent for movie encoding).



PANGU far (left) and near (right) images with LUT remapping to 4-bits

System requirements

PANGU can be used on 64-bit Windows or Linux PCs, and on macOS using a commercial virtual machine. GPU support with OpenGL drivers is needed for many features such as dynamic shadows, the atmosphere model and the physics-based camera model. A fast CPU, GPU and plenty of RAM are essential for achieving the best performance.



Deimos shape model (left) and PANGU-enhanced version (right)

Availability

PANGU v6 includes scenarios ranging from purely synthetic surfaces to real models of the Moon, Mars, Phobos and Itokawa. Example videos can be found at www.pangu.software where users of ESA projects can register to download the software. PANGU is freely available for use on ESA projects. For other projects, licences and support can be purchased from STAR-Dundee with further details available at www.star-dundee.com/pangu.

PANGU was developed by the University of Dundee with support from the European Space Agency (ESA).

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