MODELLING SPACECRAFT ILLUMINATION AND THE EFFECT OF SPECULAR, DIFFUSE AND MULTIPLE REFLECTION ON PHOTOELECTRON EMISSION

EXTENDED ABSTRACT

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ABSTRACT

Emission of photoelectrons by the sunlit surfaces of a spacecraft directly affects the spacecraft potential and the plasma environment of the spacecraft. The illumination of the spacecraft is normally calculated within the spacecraft-plasma interaction simulation and typically only includes direct illumination and coarse shadowing effects. An approach is presented that can be used to accurately model the illumination of the spacecraft and thus the photoelectric effect and its effect on the total charging of the spacecraft.

1. INTRODUCTION

The illumination model can use either the tetrahedral mesh of the spacecraft used in the spacecraft-plasma interaction model or a more complete spacecraft geometry if available. The illumination of the spacecraft is calculated using a GPU based ray tracing method to take into account the effect of both specular and diffuse reflection, of multiple reflections and the apparent size of the sun. The illumination of each facet of the spacecraft is then generated and combined into an illumination map. This data can be used by the spacecraft-plasma interaction simulation directly in place of its current illumination model.

The approach and its integration with the PTetra[1] spacecraft-plasma interaction simulation is demonstrated using the Solar Orbiter spacecraft. The illumination of the Solar Orbiter is calculated, taking into account multiple reflections of both diffuse and specular nature. This illumination map is then used in PTetra at no extra runtime cost. An extension of this approach using a more complex spacecraft geometry and mapping its illumination to the simplified mesh is also demonstrated, allowing for the decoupling of the geometry used for calculating illumination from that used in the spacecraft-plasma interaction model.

2. RAY TRACING

The illumination of the spacecraft is calculated using a Monte Carlo ray tracing method. The method consists of calculating how a large number of test rays intersect with the spacecraft. All of the rays are assumed to come from the direction of the light source. Frequently the rays are assumed to be parallel but this does not need to be the case and the apparent size of a source of light can be taken into account, such as in this work with Solar Orbiter at perihelion. The point where each ray first intersects the spacecraft is calculated, this means that both shadowing and self shadowing are taken into account. The other principle benefit of this method is its ability to calculate how light is reflected from reflective surfaces, with no restriction on how many reflections may be calculated.

The reflection of the rays can be diffuse, specular or some mixture. Diffuse reflection assumes a random direction of each ray's reflection caused by a rough surface (on the micro scale). Specular reflection assumes a perfect mirror like surface, such that the direction of reflection depends only on the angle of incidence and the surface normal at the point of intersection. Most materials are neither purely specular our purely diffuse reflectors and more complex reflection functions must be devised but these are outside of the scope of this work.

3. ILLUMINATION MAPS

In order to create spacecraft illumination maps a detailed model of the spacecraft geometry and surface properties are required. The more detailed the model the more accurate the final illumination map will be but as a baseline the geometry used in the numerical charging simulation can be used. In order to carry out the ray tracing the direction and apparent size of the light source must be defined in the spacecraft model reference frame. Rays are then generated from this direction (or range of directions as determined by the apparent size of the light source). The rays are propagated towards the spacecraft and then the reflections calculated. This results in a dataset consisting of many millions of ray/spacecraft intersection points.

4. COMPUTATION AND INTEGRATION WITH PTETRA

The overall fidelity of the illumination map is determined by the accuracy of the spacecraft model and the number of rays used in the simulation. In order to compute as many ray/spacecraft intersections as possible the ray tracing is carried out on GPU hardware using OpenCL. The spacecraft model used in PTetra is composed of thousands of individual triangles. The illumination map itself is created by counting the number of ray intersections within each of these triangles and normalizing the value. This illumination map can then be directly used in PTetra in the calculation of photoemission with no runtime penalty.

5. RESULTS AND CONCLUSION

Initial results of this method can be found in the poster P07 by R. Marchand *"Photoelectron emission with multiple UV reflection and its effect on Solar Orbiter Solar Wind Analyzer"* and a more detailed description of the methods and a comprehensive investigation of the effect of a more detailed illumination map on the charging of Solar Orbiter will be presented in the full paper based on this extended abstract.

6. REFERENCES

1. R. Marchand. Ptetra, a tool to simulate low orbit satellite-plasma interaction. *IEEE Trans. Plasma Sci. (USA)*, 40(2):217 – 29, 2012.

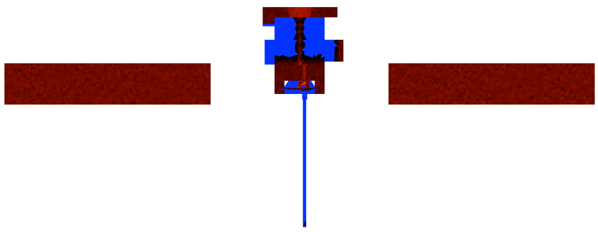

Figure 1. Purely specular reflection from dish onto surface of spacecraft bus with +15° incidence

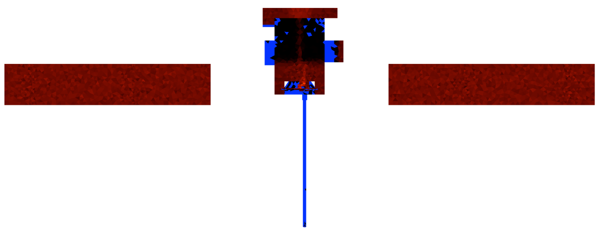

Figure 2. 50% specular and 50% diffuse reflection from dish onto surface of spacecraft bus with +15° incidence.

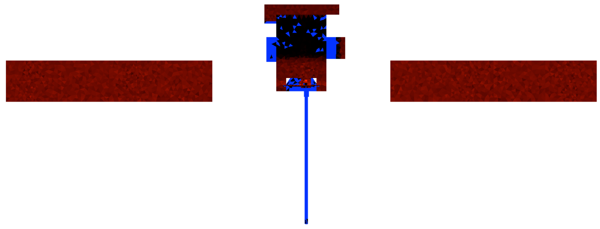

Figure 3. 100% diffuse reflection from dish onto surface of spacecraft bus with +15° incidence angle

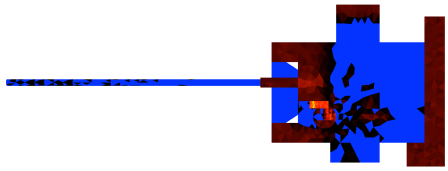

Figure 4. Effect of facets on a cylindrical structure causing unevenly distributed reflections

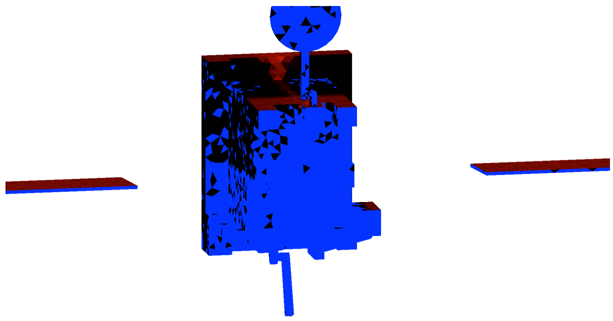

Figure 5. 50% specular and 50% diffuse reflection from dish onto surface of spacecraft bus with +15° incidence alternate view

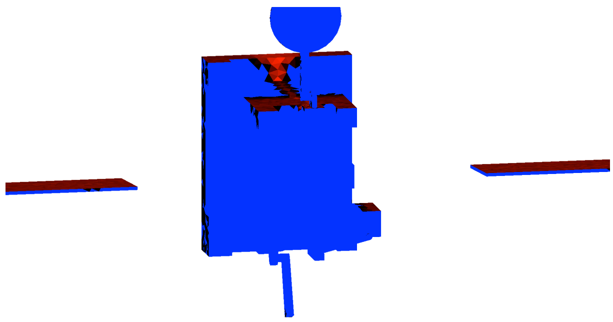

Figure 6. Purely specular reflection from dish onto surface of spacecraft bus with +15° incidence