Deepspace Interplanetary Navigation Operations Colorado Research EXplorer (DINO C-REx)

DINO C-REx Technical Memorandum

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SYSTEMS ENGINEERING REPORT 4.9: DINO C-REX BEACON LIGHTING MODEL

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Status: Initial Version
Scope/Contents
Description of the DINO C-REx camera module's object model as it applies to time integration.

Rev:	**Change Description**	**By**
1.0	Initial Release	Joe Park
1.1	Edited to reflect changes from Fall 2017	Matt Muszynski

Contents

1 Overview

The goal of the DINO C-REx (Deep Space Interplanetary Nav Ops Colorado Research Explorer) project, is to explore performance of deep space cubesats via optical navigation. To achieve this, lighting simulation of multiple celestial bodies is required. The general process and methodology is outlined in this document along with a comparison of DINO C-REx results to external sources.

The following sections address the implementation of the Lighting Simulation Module in in order to satisfy the requirements as shown in the DINO C-REx Requirements Tracability Matrix. The Lighting Simulation Module is limitied in functionality to model the illumination of celestial bodies as done by physical mechanisms without taking camera effects into account. The only dependency to the camera is to limit the illuminated surfaces to those that are within the field of view of the navigation camera.

2 Block Diagram

The Basilisk Lighting Simulation module has the functionality as described below in the block diagram shown in figure 1.

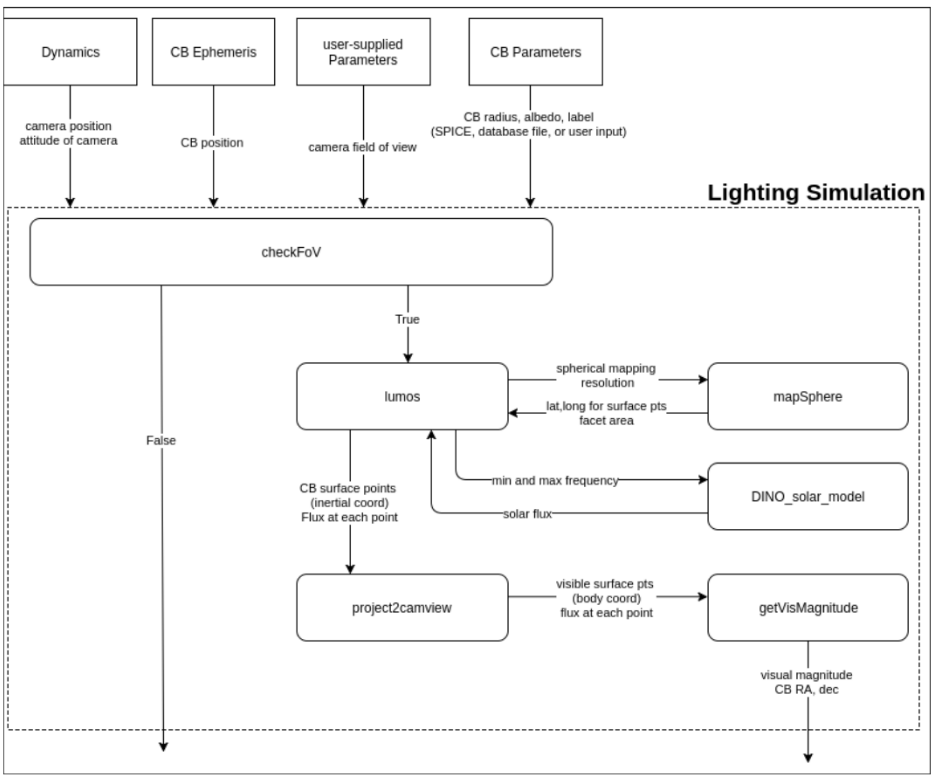

Fig. 1: Lighting Simulation Module Block Diagram

Fig. 1: Image distance quickly approaches object distance, giving justification for using the approximationsin this derivation.

3 Semi-Spherical Mapping

Before any spherical body can be illuminated, its surface first needs to be mapped. Due to equal area assumptions later on in the calculation of the net flux, the celestial body is mapped with evenly spaced latitudinal points with adjacent longitudinal points equidistantly spaced. In order to find the area of each facet, the semi-spheres total area is simply divided by the number of surface points as shown in the below equation. Extra steps were taken to place each surface point at the center location of the facet it represents. As a result of this the shown surface points do not reach the edges of the semi-sphere. Additionally, there is a small error at the highest and lowest latitudes, as the surface points should represent half the surface area of the points at other latitudes (triangular facets as opposed to quadrilateral facets). Both issues are mitigated by having a higher resolution mapping. The implementation of the code in mapSphere allows for variable resolution with the number of latitudes points to map and the number of longitude points at the equator to map are both specified. The below figure demonstrates the results of spherical mapping at two different resolutions.

$$Area_{facet} = \frac{(2\pi r_{CB}^2)}{n_{facets}} \tag{1}$$

4 Flux Calculation at the Surface Point

The calculation of the reflected flux at each surface point is done through the use of the inverse square law and the geometric albedo. The albedo model currently implemented by the Lighting Simulation module is a simple geometric albedo. A single value constant is assumed for the entire surface of the body. The reflected irradiance follows the Lamberts cosine law as shown in the below equation. Note that this reflectance model is only dependent on the solar phase angle to the surface point and is independent of the observer location.

$$Flux_{incident} = Flux_{SolarRef}\left(\frac{d_{beacon2sun}}{d_{SolarRef}}\right) \tag{2}$$

$$Flux_{facet} = Flux_{incident} * \cos\theta_{Solar} * Albedo_{geometric} \tag{3}$$

5 Coordinate Transformations and Visibility Checks

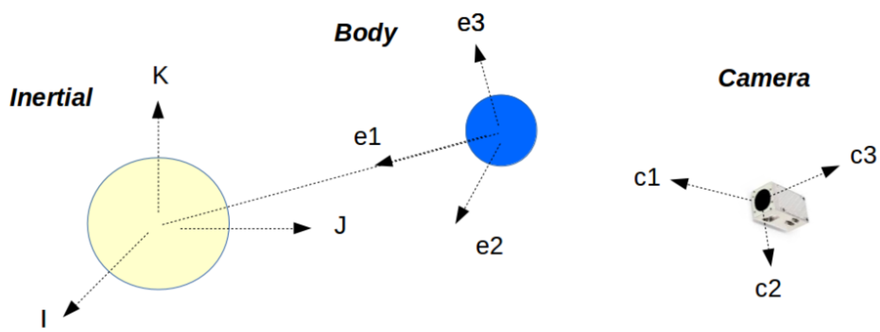

Fig. 2: Image distance quickly approaches object distance, giving justification for using the approximationsin this derivation.

In order to properly represent the illuminated target beacon in inertial space, coordinate transformations are required. Additionally, due to the varying relative locations of the celestial body to the observer, not all illuminated facets of a given body will be visible to a camera. In order to remove the non-visible facets from future calculations, an additional check needs to be done on all surface points of the sphere. A description of the frames used are included below as well as in figure 2.

The mapping of the sphere and the calculation of the flux decay due to the geometric albedo is first done in the target beacon body frame. This is defined with the $+$e1 direction towards the sun. The other two directions are notional as the illumination is axially symmetric. The body frame is then transformed into the same heliocentric inertial frame as the input position parameters of the spacecraft and target beacons. Future work with occultation checks will be done in this frame. Additionally, the inertial right ascension and declination are calculated with positions in this frame.

The final coordinate frame utilized is the camera frame. This is defined by the attitude description provided as a parameter by the spacecraft model and the camera model. This frame is defined with the camera boresight as $+$c1, left relative to the camera as c2, and vertically upwards relative to the camera as c3. This frame is utilized in order to be consistent with the camera model. Determining whether surface points are visible to the camera are done in this coordinate frame. Surface points are considered not visible to the camera, if it either lies outside the camera field of view or if the surface normal vector has a greater than 90° phase angle with the camera line-of-sight vector. This is checked with the equation below.

$$\theta_{cam} = acos(\hat{e}_{cam-LOS} \cdot (\hat{e}_{surface-norm}) \tag{4}$$