3   WP3000. IMAGING LIDAR SIMULATOR INTERFACE BY P.C. YUEN, UCL/MSSL

1. Introduction

The design and development of Imaging Lidar Simulator Interface are provided in this report. The objectives of development are listed as follows:

- Develop black-box interface between LTL Lidar equation solver[1] and UCL MCRT ray-tracing system[2].
- Combine the canopy model output with the Lidar instrument noise.
- Operate two wavelengths such as *532nm* and *1064nm*.
- Visualize the reflectance waveform vertical profiles.

The interface development is complete and there is a plan to submit response to NERC CEOI Open Call in September 2008.
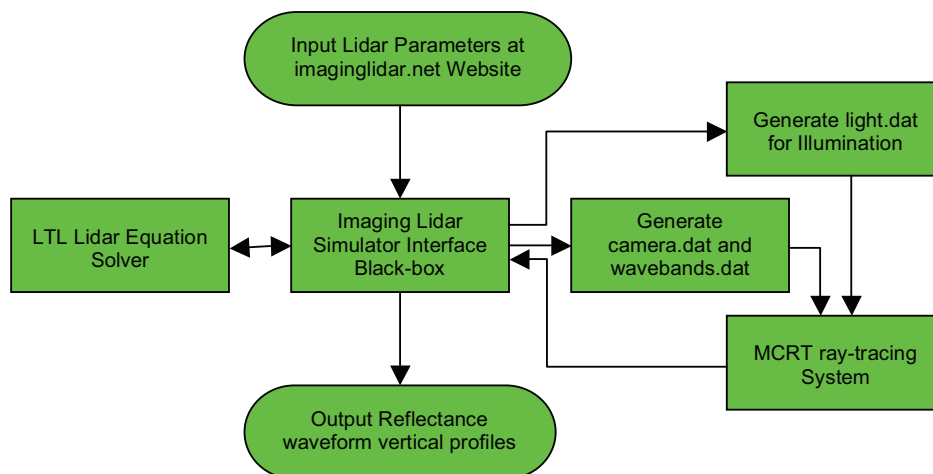
2. System Design

Figure 1: Imaging Lidar simulation system diagram

Figure 1 shows that the system structure of imaging Lidar simulation. This Imaging Lidar simulation system has integrated the MCRT ray-tracing software and LTL Lidar equation solver together. Its user interface at the website http://imaginglidar.net allows user's parameters to be input, and to execute the software online. After the parameters are submitted, the Imaging Lidar Simulator Interface Black-box software generates the light.dat file for illumination, and also the camera.dat file and the wavebands.dat files for Lidar simulation control. By transferring the information to MCRT ray-tracing system and LTL Lidar equation solver for signal processing, the Interface Black-box is capable of the visualization of the range data, reflectance data and reflectance waveform vertical profiles. Since the Imaging Lidar simulator has been developed successfully, it is now ready for the Earth Observation Satellite/Airborne

operational simulations and space mission simulations. Its bi-spectral wavelengths functionalities are able to monitor the canopy coverage, global biomass and carbon cycle. In addition, there are many enormous opportunities for Earth Observation simulation, and other potential space programme simulation applications.

3. Simulator Interface Black-box Architecture

The development of Imaging Lidar simulator interface incorporates with the proven methodology. Figure 2 presents the Interface Black-box architecture in ISO19501 standard, a Use Case diagram of Unified Modelling Language (UML). The object oriented (ood) approach is used in the following design.

Firstly, the imaging_lidar_simulator_interface object handles all the man-machine interfaces via internet.

Secondly, the object lidar.cgi is a parser to interpret the user's parameters. It then generates the data objects (camera.dat, light.dat and wavebands.dat) to kick-start next object MCRT_ray-tracing_system, the Monte Carlo Ray Tracing software.

Thirdly, the results.dat data object plus other data objects (including pulse.dat, cameraImage.hips, cameraPsf.hips and lightPsf.hips) are produced when the wait period is elapsed. The results.dat data object feeds into the LTL_Lidar_equation_solver object for generating the realistic Imaging Lidar Simulation results.

Finally, the visualization_output object provides the display of range data, reflectance data and Monte Carlo ray traced results.
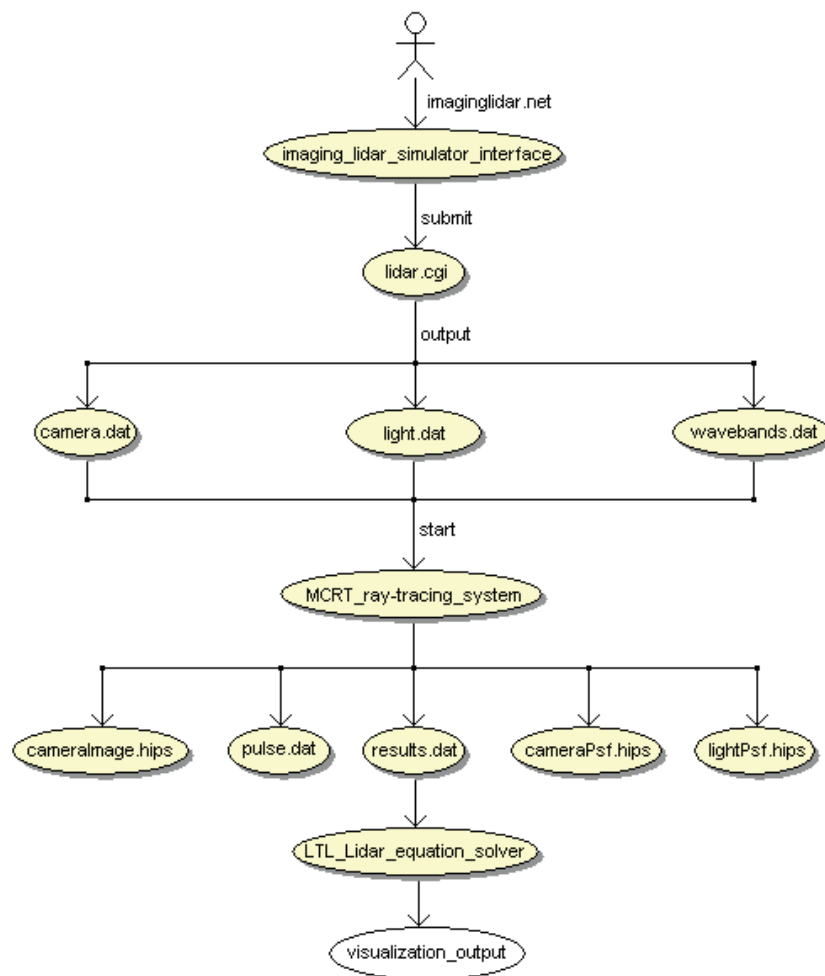
Figure 2: Imaging Lidar simulator interface black-box architecture

3. **Imaging Lidar Simulator User Interface**

In the imaginglidar.net website, user enters the illumination and camera parameters for Imaging Lidar Simulator. After the submit button is pressed, its parameters are immediately sent for execution, there is a "Wait" prompt displayed on-screen. It takes a few moments to produce the results web page in below Section *6* On-screen Simulation Results.

Illumination parameters correspond to the light.dat data file. They include Latitude and Longitude in degree; Azimuth, Zenith and Twist in radians. There is a default Altitude at *400,000 km*. Same values and units of measurement apply to Camera Parameters corresponding to the camera.dat data file. The Lidar Pulse Length in Illumination Parameters normally sets to default *29979.2458 mm*. Similarly, the Pulse Sample Rate defaults to *420 Hz.* The Lidar pulse Resolution has the samplingPattern.size equal to *378* pixels by default.

The camera.dat file shares the same parameter in Resolution at Illumination parameters. The Number of Bins (lidar.nBins in camera.dat file) is defaulted to *150*. The Sample Rate (lidar.binStep) is set to default *550* bin steps.

For the wavebands.dat setting, it inputs from Wavebands default to *532* nm for the top frame. The bottom frame is set twice in size to become the default value *1064 nm*.

Figure 3: Imaging Lidar Simulator at URL http://imaginglidar.net

4. Lidar Equations

$$P_{i,S} = E_{0,i} \cdot T_T \cdot T_{R,NF} \cdot R_{Lidar} \cdot \cos(\theta_{across}) \cdot \frac{A_R}{(Z_S - Z_{SSE})^2} \cdot T_{R,F}(\lambda_i) \cdot [T_{a,m}(Z_{SSE}, Z_{TOA}, \lambda_i)]$$

The terms of the expression have the following meaning:

$E_{0,i}$ is laser pulse energy, in photons.

T_T is Lidar transmitting path optical efficiency (from laser source to telescope).

$T_{R,F}(\lambda)$ is Lidar receiving path optical efficiency due to filters' contribution, interference (IF) filter and Capacity Stabilized Etalon (CSE) filter.

$T_{R,NF}$ is Lidar receiving path optical efficiency from telescope to filters.

R_{Lidar} is on-ground LIDAR reflectivity.

θ_{across} is across-track angle to nadir [*deg*].

A_R is telescope area [m^2].

Z_S is spacecraft altitude [*m*].

$T_{a,m}(Z_{SSE}, Z_{TOA}, \lambda)$ is total column atmospheric transmission due to aerosol and molecular backscattering, $T_{a,m} = e^{-2\int_0^\infty \alpha + \beta}$ where α is the aerosols backscattering coefficient and β the molecular scattering coefficient.

The noise is given as follows:

Background photons $\dfrac{dP_B(\lambda)}{d\lambda} = \rho \cdot \dfrac{dE_{Sun}(\lambda)}{d\lambda} \cdot \dfrac{TFOV^2}{4} \cdot A_R \cdot \cos\theta_S \cdot \left[T_{a,m}(Z_{SSE}, Z_{TOA}, \lambda)\right]$

where ρ is albedo of reflecting surface.

$\frac{dE_{Sun}(\lambda)}{d\lambda}$ is Sun spectral irradiance at *1 AU [W·m⁻²·sr⁻¹·nm⁻¹]*.

$TFOV$ is telescope field of view [*rad*].

θ_S is Sun incident angle [*deg*], depending on the orbit parameters i.e. LTDN

For calculating the total noise, total number of background photoelectrons at instrument output is a combination of the solar background and detector noise as shown in the following equation:

$$n_{i,B_T}^e = \left[QE \cdot P_B \cdot \left(\frac{\lambda}{h \cdot c_0}\right) + \frac{1}{2F} \cdot \left(\frac{QE\lambda}{h \cdot c_0}\right)^2 \cdot NEP^2\right] \cdot t_I = n_{i,B}^e + n_{i,D}^e$$

where P_B is the solar background power [*W*].

F is the excess noise factor of the detector.

NEP is the noise equivalent power of the detector after amplification [*W·Hz⁻⁰·⁵*].

QE is the detector quantum efficiency.

Therefore, the total noise is $\sigma = \sqrt{(n_{i,S}^{e} + n_{i,B_T}^{e}) \cdot F}$

5. **On-screen Simulation Results**

MCRT ray-tracing system generates results.dat to feed into the Lidar equations to simulate the realistic Lidar environment. An on-screen results web page displays the following data:

(a) Header which provides the information of data length, number of columns and wavebands. For example,

integral results, ordered by: distance (rows 152) scattering order (cols 2) waveband (frames 2)

indicates that there are *152* sample data in two columns and two wavebands.

(b) Waveband 1, it is located at the top frame

```
# Wavelength: 5.320000e+02
# Scattering Order:
# 1 2
7.999884e+08        0.000000e+00
7.999890e+08        0.000000e+00

8.000143e+08        2.696881e-04
8.000148e+08        2.408145e-04
8.000154e+08        2.010014e-04

8.000710e+08        0.000000e+00
8.000715e+08        0.000000e+00
```

This gives the results at wavelength *532nm.*

(c) Waveband 2 which is placed at the bottom frame

```
# Wavelength: 1.064000e+03
# Scattering Order:
# 1 2
7.999884e+08        0.000000e+00
7.999890e+08        0.000000e+00

8.000143e+08        6.342161e-04
8.000148e+08        7.464481e-04
8.000154e+08        6.518757e-04

8.000710e+08        0.000000e+00
8.000715e+08        0.000000e+00
```

It has the wavelength at *1064nm.*

(d) Two data column. First column represents range in meter. Second column provides the reflectance. Figure 4 shows the results of waveband 1 and waveband 2 which both have the Gaussian properties. The simulation also includes the solar background noise and the detector noise. This

characterizes the data to emulate the realistic imaging Lidar environment. Lidar waveform vertical profiles between range and reflectance are produced online.
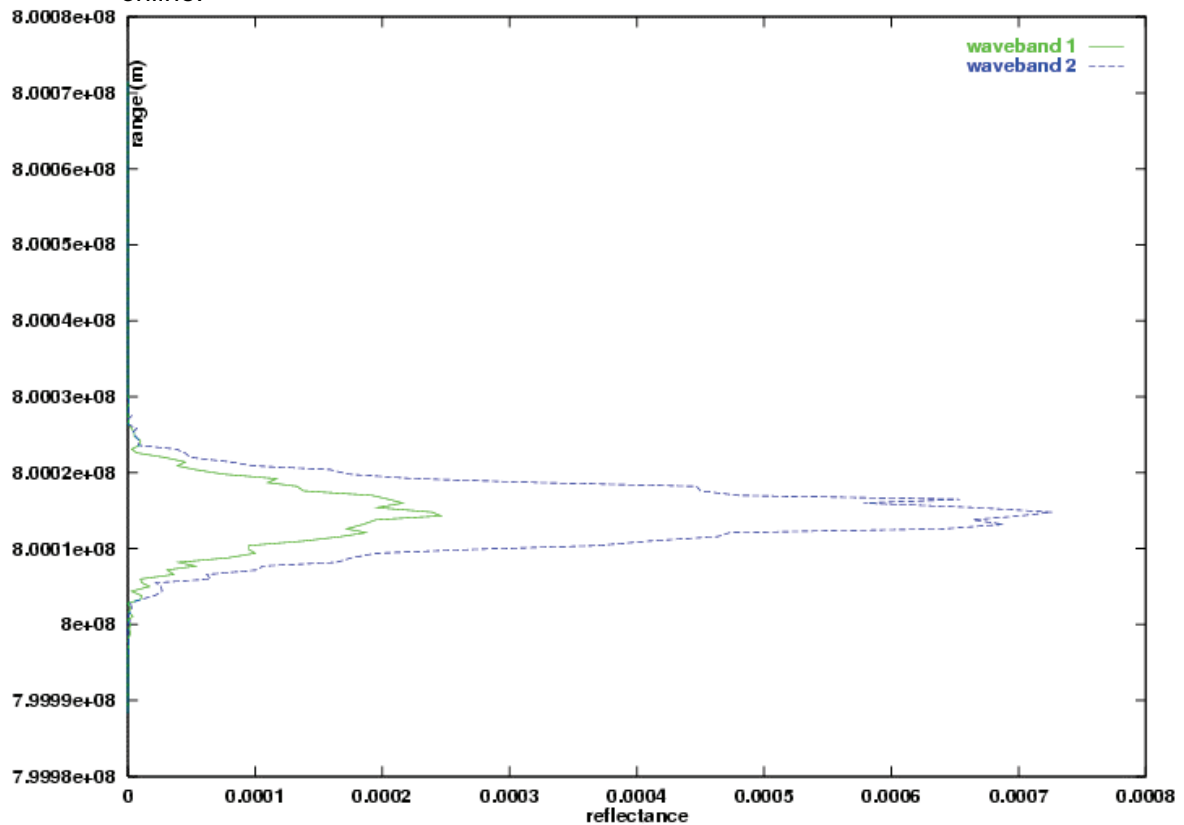

Figure 4: Lidar waveform vertical profiles

6. Conclusion

The online simulation system developed at UCL incorporates Lidar design parameters, atmospheric transmission and Monte Carlo ray-tracer to represent multiple scattering within a dense vegetation canopy. The completed product includes:

- Interface to LTL sensor mathematical model.
- Packaged LTL sensor maths-model and UCL vegetation canopy Lidar simulation system.
- Built interface to atmospheric and sensor model.

Since the Lidar simulation system to interface the engineering Maths model with the MCRT ray-tracing scene simulator has been developed, it is now available online on the internet (http://ImagingLidar.net). There has been suggested for design expansion in the future; it is recommended to further develop the most sophisticated Lidar simulation system, unique online web-based simulator for testing different Lidar designs, different vegetation canopy mathematical models and different scientific experiments.