TERAHERTZ EMISSION OF THE LUNAR SURFACE: FORWARD MODELING.

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Introduction: Since 1960, humanity has explored the moon. From that time and until now, our second wave and the ultimate goal of moon exploration will be removing the ambiguities and achieving a comprehensive understanding of the physical conditions on the moon. We are on the way to the moon, and we are experiencing the greatest adventure of our time. First of all, it is crucially important to probe the surface features of the moon. Pursuing this objective, numerical remote sensing techniques, being active and passive [1-2], have been contributed to unveil the physical characteristics of the lunar surface and eventually subsurface to a certain depth. It is worth noting that either in the first or the second wave of lunar exploration, terahertz wave still acts as a probing gap, among the electromagnetic spectrum, terahertz wave, which lies between microwaves and infrared light waves, is called the "the terahertz gap." It merges the neighboring spectral bands such as the millimeter-wave band, the sub-millimeter-wave band, and the infrared band, thus sharing some characteristics. With an attempt to fill in the exploring gap in both electromagnetic spectrum and lunar exploration, our research group is initiating a terahertz lunar exploration mission, which is named as Lunar Terahertz Surveyor for Kilometer-scale Mapping (TSUKIMI), led by National Institute of Information and Communications Technology (NICT) and collaborated with the University of Tokyo, Japan Aerospace Exploration Agency (JAXA), Osaka Prefecture University, and the venture companies of SpaceBD and iSpace. The key milestones of this prominent mission are to develop the micro-satellite terahertz radiometer with the agilities of dual-frequency, dual-polarization, and multi-angle observation for lunar exploration, followed by monitoring the terahertz wave lunar brightness temperature globally and spatiotemporally, and retrieving the physical parameters of the lunar surface and subsurface including dielectric constant, water distribution map, topographic roughness, and so forth.

We begin with the development on the forward modeling of the interaction between terahertz wave and the lunar surface and subsurface, which acts as a central kernel for guaranteeing the better implementation of terahertz wave observation, particularly in support of the incoming TSUKIMI mission, as well as to help design the future serials for terahertz wave lunar exploration and ultimately to assist the interpretation and retrieval on the physical parameter of the lunar surface.

Forward Modeling: The schematic diagram of the forward modeling is illustrated in Figure 1. In the designed forward modeling, terahertz scattering from the lunar surface will be investigated numerically and experimentally in terms of the lunar roughness spectrum, horizontal and vertical roughness scale, together with the development of lunar dielectric constant modeling at terahertz region, with particular attention on the parameters of lunar bulk density, composition, frequency and temperature dependencies, and water fraction. We apply the well-known Advanced Integral Equation Model (AIEM) [3-4] to calculate HH and VV-polarized scattering coefficients and emissivity, both coherent and incoherent. The dense media radiative transfer model for volume scattering inside of the lunar regolith and the matrix doubling method accounting for multiple scattering in the lunar regolith are incorporated in the forward modeling. Through the laboratory experiment, the lunar dielectric constant modeling at terahertz region will be developed, the sensitivity analysis on both lunar surface parameters and probing parameters will be thereafter carried out.

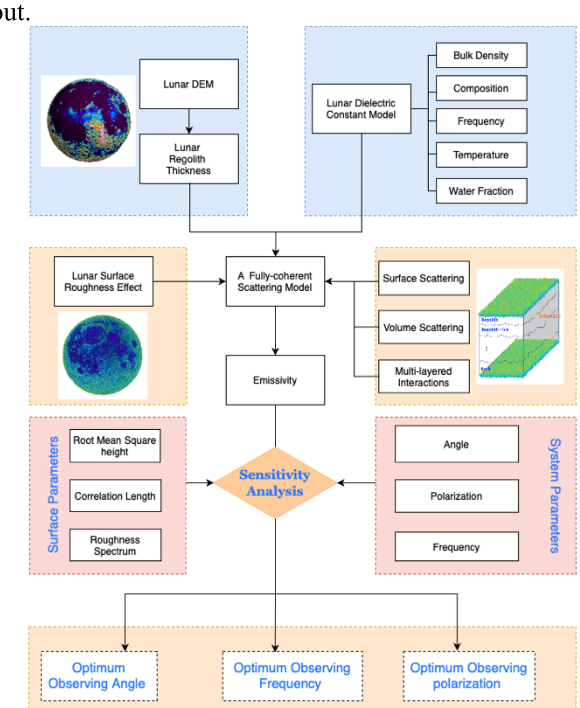

Figure 1. *The schematic diagram of the forward modeling.*

Numerical simulation: To the best knowledge of the authors, until now, the appropriate roughness spectrum for describing the lunar surface is not attainable yet. Therefore, we intuitively examine three widely applied roughness spectrums, say gaussian, exponential, and 1.5 power, aiming to investigate the effects of different root-mean-square (RMS) heights and correlation lengths on terahertz scattering from the lunar surface. Meanwhile, referring to the lunar dielectric constant [5-6] at microwave region, which is generally agreed that the real part of the lunar dielectric constant is related to lunar bulk density, approximately ranging from 1.3g/cm^3 to 2g/cm^3, while the loss tangent is determined by the abundance of $FeO + TiO_2$, bulk density, and frequency. We adopted the dielectric constant from the given range in the simulation. The simulation results are presented in Figure 2 and Figure 3.

Laboratory measurement: To investigate terahertz scattering and emission from the lunar surface, we initially simplify the sample from the gaussian rough surface. The reference surfaces made from Durable Resin V2 by 3D printing with the prescribed power spectral density and height probability density function, along with the RMS heights and correlation lengths have been fabricated. The preliminary experiment regarding the dielectric constant of the material at terahertz is conducted by THz-TDS. The experiment result is given in Figure 4. For each measurement, we repeated it three times for guaranteeing the credibility of the experiment. Since the surface of the undertest sample has a slight roughness, we examined the roughness effect on the dielectric constant measurement by rotating and measuring the same undertest sample at the angles of 0º, 90º, 180º, and 270º. We next conducted the surface roughness experiment by T-Ray 4000. The experiment scenario and the result are presented in Figure 5.

Conclusions and future work: Along with the TSUKIMI mission, we established the forward modeling of the interaction between terahertz wave and lunar surface and subsurface. The preliminary experiments with regard to the dielectric constant and rough surface have been conducted. In future work, the lunar simulants with the prescribed physical parameters in terms of the roughness condition and the dielectric property will be utilized for more sophisticated experiment.

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References:

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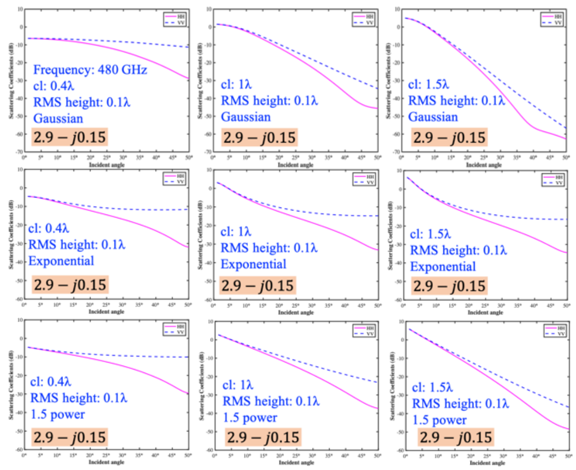

Figure 2. *Scattering coefficients.*

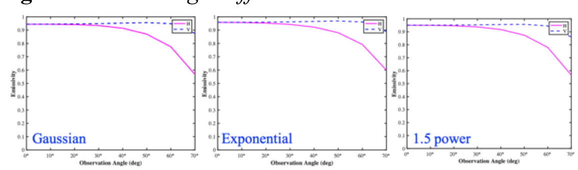

Figure 3. *Emissivity.*

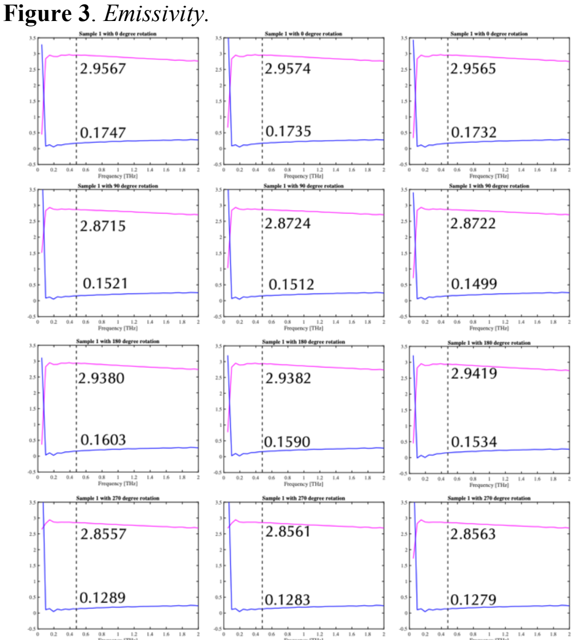

Figure 4. *Dielectric constant.*

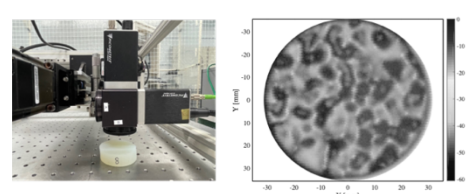

Figure 5. *Experiment scenario and corresponding result.*