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MODELING AND SIMULATION OF EMISSIVITY OF COMPONENTS OF VEGETATION

[1]SELIM SEKER,[2]ALI SEN, [3]NEVZAT TARHAN

[1,2]Department of Electrical-Electronics Engineering, Uskudar University, Istanbul, Turkey
[3]Uskudar University, NPIstanbul Hospital, Istanbul, Turkey
E-mail: [1]selim.seker@uskudar.edu.tr, [3]nevzat.tarhan@uskudar.edu.tr

Abstract – The Electromagnetic radiation that is emitted by the object carries specific properties about it. Emissivity is one of the frequently used passive remote sensing parameters for objects. In literature, remote sensing of vegetation includes different methods that are based on measurements with active and passive remote sensing. In this study, vegetation components are considered separately that leaves are modeled as dielectric disks and branches and trunks are modeled as cylinders for passive remote sensing for the first time in the literature. Emissivity and absorption cross section equations of geometrically facilitated vegetation are found out using two approximations. Emissivity for leaves is calculated using physical optics approximation on disk. In branches and trunks, infinite length approximation is applied on a cylinder. To check the accuracy of calculations, absorption cross section calculation results are compared with literature studies, and good agreement is found. The emissivity of human is simulated and the effects of each parameter are examined.

Keywords - Emissivity, Modeling, Simulation, Vegetation.

I. BACKGROUND

Electromagnetic radiation (EMR) reaches the earth's surface or the surface of the target matter after some loss and scattering. Physical and compositional characteristics of the medium affect the action of the radiation Objects can exhibit different behaviors against the radiation depending on the wavelength. Therefore, it can be said that different wavelengths provide the detection of different properties of the target object. Different from the emissivity calculation from the measured power, in this work, the emissivity of the object is calculated reversely like calculation from the object using its absorption cross section. Estimation of the emissivity before the measurements allows the prediction of the specification of the object and its content [1-3].In this work, the vegetation component is modeled part by part as discs and cylinders e.g. disk model is used for modeling vegetation leaves and cylinder geometry is utilized for branches and trunks. Physical optics and infinite length approximations are used for the derivation of the absorption cross sections. Absorption cross section derivation is one of the key points to define emissivity. The emissivity of the defined vegetation components are simulated with changing different parameters account in real life. The emissivity of vegetation is simulated for different conditions to provide applicable useful model results. The simulation results of this work are compared with literature. Obtained simulation results provide data with a much faster method than the experimental process.

II. EMISSIVITY OF COMPONENTS OF VEGETATION

Emissivity is the description of the radiation emission ability of the subject surface. Emissivity is a dimensionless relative quantity that changes between zero and one. The emissivity value of one belongs to the blackbody radiation, and there is no absolute zero emissivity in real life, all objects emit radiation to some extent.
The emissivity of a material can be defined by means of energy conservation relation. The emissivity of the vegetation component formula is [3-6]

$$e_q(\theta) = 1 - R_q(\theta) - T_q(\theta) \tag{1}$$

where

$$R_q(\theta) = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi/2}\sum_{p=h,v}\frac{\sigma^o_{pq}(\theta,\theta_s,\phi_s-\phi)}{\cos\theta} \times \sin\theta_s d\theta_s d(\phi_s-\phi) \tag{2}$$

$$T_q(\theta) = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi/2}\sum_{p=h,v}\frac{\sigma'^o_{pq}(\theta,\theta_s,\phi_s-\phi)}{\cos\theta} \times \sin\theta_s d\theta_s d(\phi_s-\phi) \tag{3}$$

The average scattering patterns of randomly oriented cylinders and discs show that when cylinder dimensions are large with respect to the wavelength, bi-static scattering cross sections are peaked in the forward direction. Dependency on the sampling of scattering angle causes the calculation to be problematic; therefore, an approximation is built for transmission and reflection behavior of the object. The average scattering patterns display a forward behavior and it has been assumed that cylinders behave like absorbers. The resulting transmission function equation for the approximate absorbing object is given as [3],

$$T_q^A(\theta) = e^{-\frac{n\Delta z\sigma_a^q(\theta)}{\cos\theta}} \tag{4}$$

where n is the number of scatterers per unit volume and Δz is the height of the layer. Because the scatterer is considered as an absorbing object, following approximations in (2) and (3) are also provided [1,5], $R_q(\theta) \ll T_q(\theta)$

$$T_q(\theta) \approx T_q^A(\theta) \quad (5)$$

Looking back to the first equation in the definition of emissivity of vegetation, the resulting

$$e_q(\theta) \approx 1 - T_q^A(\theta) \quad (6)$$

The single particle cross section, which causes this absorbed power, is called an absorption cross section. A definition for the scattering cross section can be considered in the same way. The total cross section term is the sum of scattering and absorption cross section. Emissivity and back scattering evaluations of vegetation require a model that relates these characteristics with definable structures in theory. Vegetation components are leaves, branches, and trunks; that is considered as absorbing and scattering objects. Leaves of the vegetation are modeled as a thin and thick layer of disk shape with complex permittivity. The cylindrical shape is taken for branches and trunks.

2.1. Modeling of Leaves as Thin and Thick Disks

Leaves of vegetation are modeled as disks. Physical optics (PO) approximation is proper to be employed at this step of the calculation since the cross section of the disk is large compared with the wavelength. A large cross section with respect to wavelength and thickness provides the advantage of non-effective edges on the field. In PO approximation, it is assumed that if the disc axes are large with respect to the wavelength of the incident wave. The principle behind the approximation is to replace the unknown fielded object to a specific solvable object and then to use resulting field description in the object to obtain absorption cross section . Absorption cross section of the disk is founded as

$$\sigma_a^q = k\varepsilon_r'' ab\delta \times \begin{bmatrix} \left(\left|e_q^+\right|^2 + \left|e_q^-\right|^2\right) \dfrac{\sinh(k\delta\,\mathrm{Im}(\beta_z))}{k\delta\,\mathrm{Im}(\beta_z)} \\ + \mathrm{Re}\left(e_q^+ \hat{q}_\in^+ \cdot e_q^{-*} \hat{q}_\in^{-*}\right) \dfrac{\sin(k\delta\,\mathrm{Re}(\beta_z))}{k\delta\,\mathrm{Re}(\beta_z)} \end{bmatrix} \quad (7)$$

where {Re} and {Im} are the real and imaginary part operators of complex components. The parameters are defined in reference [4-5].

2.2. Modeling of Branches and Trunks as Cylinders

Branches and trunks of the vegetation for absorption cross section have an expression similar to leaves mentioned in the previous section, therefore branches and trunks are modeled as a cylinder to calculate absorption cross section [6-7]

$$\sigma_a^q = 4\pi k\varepsilon_r'' l \times \left(\sum_{n=-\infty}^{\infty} \left|e_n^q\right|^2 Y_n + 2\left|c_n^q\right|^2 Y_{n+1} + 2\left|d_n^q\right|^2 Y_{n-1} \right) \quad (8)$$

The parameters are defined in reference [6-7].

III. MODEL SIMULATION

The aim of this chapter is to present the accuracy of the created model by comparisons. In literature, disk and cylinder models are used for absorption and scattering cross section calculations with various materials. In these studies, the absorption cross section has been also calculated for vegetation parameters using similar approximations; however, the simulation tool and method are different therefore the comparison of results with literature provides accuracy of the model. In the simulation, the angle of incidence is taken as 0o and the disk radii are 7.0 cm. The thickness of the disk is 0.3 mm. The frequency range is selected as low frequency and high frequency values included from 1 GHz to 40 GHz. As we observe two curves in Fig. 1., it is seen that both graphs increase with decreasing slope. This is an expected situation. At low frequencies, meanly from 1 GHz to 5 GHz, the shape of the graphs are similar, however, absorption cross section values are different. Frequencies around 5 GHz absorption cross section values become consistent. After 10 GHz frequency, the slope is decreasing. .

In the second comparison, the absorption cross section has been calculated using parameters from NASA report on high frequency scattering of dielectric disks [4-5]. Horizontal and vertical polarizations are both taken into account. The comparison has been done for three frequency values. 1 GHz, as low frequency, 4 GHz as mid and critical frequency, and lastly 7 GHz, as high frequency is calculated. 4 GHz is mentioned as critical frequency, because of the restriction in approximation.

The thickness of the dielectric disk is taken as 1 mm, and the radius is 7 cm. The angle of incidence is $30°$ for calculations. The relative dielectric constant is taken as 36 + 13i that corresponds to leave with 70% water content.

Frequency	NASA Report	Our Model	Error %
1.0 GHz	0.00276	0.0025	9.42
4.0 GHz	0.00318	0.0032	-0.629
7.0 GHz	0.00264	0.0026	1.515

Table 1. Comparison of calculated absorption cross section with NASA report for horizontal polarization

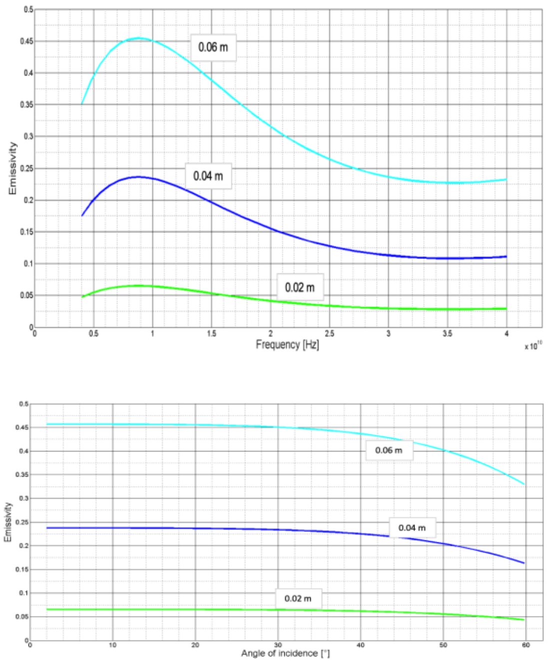

Figure 1. Emissivity versus frequency and incidence angle for leaves with three values of leaf radius for horizontal polarization.

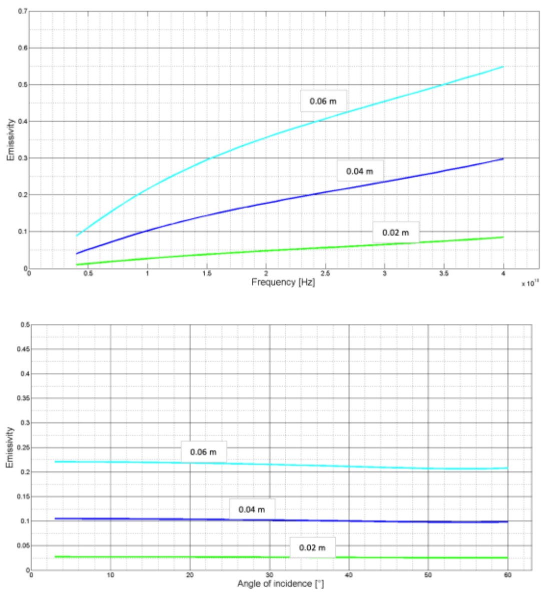

Figure 2. Emissivity versus frequency and incidence angle for leaves with three values of leaf radius for vertical polarization.

In Table 1, three values of the absorption cross section of the disk are given with frequencies. At 1 GHz, the calculated absorption cross section is about 0.0025 and for NASA report, that value is 0.00276. The error is about 9.4% that is not a small error. However, if the dimensions of the disk are considered, the radius of the disk (0.07 m) is much smaller than the wavelength (0.299 m). Therefore, the assumption made in the absorption cross section approximations part is not valid. Results might be improved by another method. At larger frequencies, for 4 GHz and 7 GHz, the error percentage is smaller enough to accept that the calculated results for the model are accurate. At 4 GHz, the error is 0.6% and for 7 GHz, the error is 1.5%.

3.1. Leaf Model Emissivity Simulations

The model is simulated for horizontal and vertical polarizations of the wave. Different thicknesses and diameters for leaves are selected in simulations. Thick and thin leaves are considered according to the assumption that if the ratio of radius/thickness is smaller or equal to 10, then the leaf is called a thick disk. Otherwise, it is assumed as a thin disk.

The emissivity of leaf simulation with respect to frequency is given for three variables for horizontal polarization. In all, frequency is continuously changed and three curves exist for each variable. An increase in frequency results decreases emissivity in all curves except for the smallest real component of the complex relative permittivity. In Fig. 1, the frequency has been simulated for three radius values. The larger radius causes higher emissivity. The thickness of the leaf has a similar effect on emissivity. In Fig1, three curves for thickness are given. Thick leaves have larger emissivity, which is also a result of the absorption cross section. The angle of incidence has a direct effect. If the cosine factor is considered, the higher angle of incidence causes lower emissivity.

The emissivity results versus frequency graph for leaves with the thickness, angle of incidence, dielectric constant have similar shapes with different magnitudes. Emissivity decreases with an increase in the angle of incidence in curves generally. If the incident angle is large, the transmission factor is higher too. Transmission effects emissivity inversely. Larger real parts have lower emissivity values, and after some regions, emissivity decreases.

The emissivity results versus angle of incidence graph for leaves with the leaf thickness, frequency, dielectric constant have similar shapes with different magnitudes for vertical polarization. An increase in frequency results increases emissivity in all curves. In Fig. 2 emissivity versus frequency graph for leaves with three values of leaf radius for vertical polarization is given. The radius is one of the multipliers, therefore, a larger radius value causes higher emissivity. Emissivity versus angle of incidence simulations for vertical polarization stays almost stable with an increase in the angle of incidence in curves. Vertical polarization changes the effect of angle of incidence on the internal electric field and absorption cross section.

The thickness of the leaf has a similar effect on emissivity; mainly an increase in thickness increases the emissivity. Thick leaves have larger emissivity, which is also a result of the absorption cross section. The angle of incidence is another parameter. At low frequencies, smaller than 15 GHz, change in angle is not effective on emissivity. For higher frequencies, the increasing angle increases the emissivity.

In Fig. 2, emissivity is simulated with leaf radii. Similar to frequency, a higher radius has a higher emissivity value. Absorbed power increases while increasing leaf thickness. As mentioned before, the imaginary component of relative permittivity has a direct multiplier and therefore larger value increases the emissivity.

3.2 Branch and Trunk Model Emissivity Simulations

In this section, the emissivity of branch and trunks are simulated with respect to changing frequency. To some point, emissivity increases; however at higher frequencies emissivity decreases. Together with changing frequency, cylinder radius, cylinder length, angle of incidence, and complex relative permittivity is simulated to obtain specific relations between pairs. In the first graph, Fig. 3, the effects of radius and length are displayed. Thin branches have lower emissivity and trunks have higher, as it is expected from Eq. (9). Because of the volume integral of wave transformation equation, length and radius are direct multipliers. The emissivity results versus incidence angles are given in Fig. 3 too. Cylinder geometry is different from the disk geometry. Increasing angle effect, emissivity at 60° angle causes better absorption. The internal electric field constitutes the absorption cross section and emissivity. The real and imaginary parts of dielectric constant are investigated in separate graphs similarly. The imaginary part is again a multiplier of the absorption cross section. For both components, higher value causes higher emissivity.

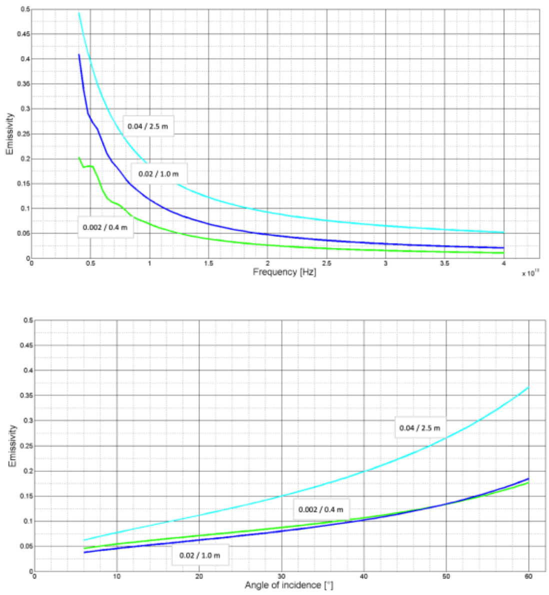

Figure 3. Emissivity versus frequency and incidence angle of branches and trunks with three values of cylinder length and radius for horizontal polarization.

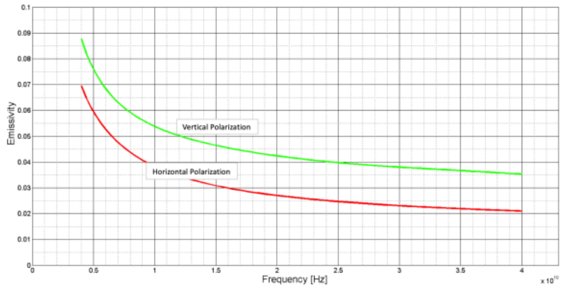

Figure 4. Emissivity versus frequency with horizontal and vertical polarizations

The incident angle is considered as the second parameter in the emissivity simulation of the branch model. With different dimensions, frequencies and dielectric constants three graphs are obtained. The obvious effect of the angle of incidence is an increase in emissivity. The geometry and therefore the effect on emissivity are different from the leaf model. In dimensional change, the angle of incidence affects the emissivity values of geometrically similar branches. At 50°, two curves intersect. The trunk has higher emissivity than others, because of higher absorption. Incidence angle affects the emissivity and absorption cross section separately. The dominant effect of geometry changes inversely with the change in the incidence angle. As frequency increases emissivity decreases in simulations. Similar to frequency simulation, larger values of real and imaginary parts result in higher emissivity values.

The emissivities of branches and trunks are simulated with respect to frequency. Vertical polarization results are similar to horizontal polarization. Cylinder geometry is different from the disk geometry; therefore, it has different results from disk model simulations. Increasing angle affects emissivity at 60° angle and causes better absorption and therefore the effect of the cosine factor is smaller. The obvious effect of the angle of incidence is an increase in emissivity. The geometry and therefore the effect on emissivity is different from the leaf model. Vertical polarization has a remarkable effect on leaf model simulations; however, for cylinder, vertical polarization results are almost the same with horizontal polarization case.

IV. SIMULATIONS OF HUMAN MODEL

In previous sections, modeling and simulations for vegetation components are discussed. Many dielectric materials including human can be modeled as cylinders. With this parametric study and code, it is sufficient for modeling of objects with known dielectric constant and dimensions. In this section, a model of human as a cylinder and simulations according to this model will be made and interpretation of the results will be discussed [7]. Using the data obtained in the literature, the dielectric constant of the human body depends on the body structure. Theparameters of the model are length=190cm. diameter=50cmand dielectric constant=32-i5.

1.The simulations of the emissivity versus frequency of modeled man with changing polarization is shown in Fig.4. The angle of incidence is taken as $45°$.

Considering the results in these figures, it appears that the emissivity decreases with increasing frequency. Vertical emissivity is higher than the horizontal polarization. If dimensions are different so that the difference between the emissivities of the models is related to the volume of the subject body. There is a direct correlation between the volume of the object and the absorption cross sections. Thus, the emissivity increases with increasing volume. The absorption cross sections are increased and emissivity increases with increasing volume in the model for man.

V. CONCLUSION

In this study, vegetation has been modeled to simulate the emissivity of vegetation. As a passive remote sensing method, emissivity and absorption cross section have been obtained using the electric field. Model accuracy is illustrated; therefore, absorption cross section equations have been simulated and calculated to make a comparison with the results from the literature. In the leaf model, the frequency has been increased from 4 GHz to 40 GHz.The wide incidence angle has a smaller value of emissivity. In horizontal polarization, the emissivity value is greater at low frequencies. In vertical polarization, higher frequencies result in greater emissivity value, therefore depending on studied frequency range, horizontal and vertical polarizations could be applied in the model. In the cylinder model constituted for branches and trunks, simulation parameters are similar. Length, radius, angle of incidence and relative permittivity are all second variables for curves. Emissivity curves for both polarizations are decreasing with an increase in frequency. Wider incidence angle causes emissivity to increase.

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