Numerical Solution for Received Power Estimation in a Wave Propagation — A Case of Ground Based C-band SAR Test

M. Nasucha[1,2], **J. T. S. Sumantyo**[1], **M. Y. Chua**[1], **C. E. Santosa**[1], **Y. Izumi**[3], **and P. Razi**[1]

[1]Center of Environmental Remote Sensing, Chiba University, Chiba 263-8522, Japan
[2]Department of Informatics & Computer Science, Universitas Pembangunan Jaya
Tangerang Selatan, Indonesia
[3]Graduate School of Environmental Studies, Tohoku University, Japan

Abstract— Despite the long history and wide application of computer simulation on wave propagation, it is found interesting that study on numerical solution to estimate the amount of received power at the receiving antenna is limited. While, in preparing a radio transmission system, including a SAR system, the estimation of received power is crucial. A good estimation on received power shall reduce the probability of an on-field failure. This article is mainly aimed to addresses several aspects in concepting the solution to this issue. In particular, a ground-based C-band SAR test scenario using a 5.3 GHz carrier and our newly designed transmitting and receiving antennas has been taken as a case as the simulation model.

1. INTRODUCTION

Computer simulation on wave propagation has been studied widely for various purposes, including the ones reported in [1–6]. Nagatani et al. [1] reported study on the propagation of ultrasonic waves for medical imaging purpose. H. B. Lim et al. [2] and S. C. Hagness et al. [3] reported their study on the propagation of microwave for the medical imaging purpose too. V. Jokovic et al. [4] addressed study on the propagation of microwave for the purpose of material heating. M. Qakir, G. Qakir and L. Sevgi [5] discussed outcome of their study on wave propagation in a context of (future) device development, especially ones involving metamaterials.

Despite the varied properties of the waves in use and the varied purposes for which the studies have been carried out, these works had a similarity: the computer simulations on the wave propagation were done for a (very) short traveling range, i.e., a few λs to tens of λs. The reason for this trend to develop is that a computer simulation for wave propagation requires a huge computation resource especially for carrying out a large number of iterations. Research work on numerical simulation of wave propagation over a large area is still limited. This kind of research was reported in [6]. In this paper B. Dowd and R. E. Diaz simulated a radio wave propagation over an area of the ocean using Finite Difference Time Domain (FDTD) method.

Beside the fact that study on wave propagation over a large area is limited, it is interesting to find that most numerical computations on the wave propagation — mostly using Finite Difference Time Domain (FDTD) method, Method of Moment (MoM) and Finite Element Method (FEM)- have not focused on the estimation on the power density at the receiving point. While, estimating power density at the receiver point is a crucial requirement, as part of the power budget planning. A good estimation on the received power density should provide confidence to a researcher or engineer in obtaining best signals.

Take an example, the importance of power density estimation is found in Synthetic Aperture Radar (SAR) remote sensing practices. The SAR remote sensing itself is usually done using a satellite, an aircraft, or a ground vehicle. An example of the usage of a useful satellite SAR data for humanity is reported in [7].

This article is aimed to address our initial work in concepting a numerical solution for estimating power density over space and time difference. A real case of ground-based SAR test conducted by our lab is taken as a model in order to show a more perceptible explanation.

2. PROBLEMS AND PROPOSED SOLVING METHOD

In this section the problem is addressed and elaborated, as well as our proposal on the method of solving it.

2.1. Problems

In a radio transmission system a power budget planning is required in order for the receiver to receive signals as desired. Harald. T. Friis is the first person worked on and published the relation between transmitted and received radio wave power in a radio transmitting system consisted of a transmitter and a receiver that are separated each other by a certain distance [8]. Following some elaboration, the Friis Formula then can be expressed as

$$Pr = \frac{Pt \cdot Gt \cdot Gr \cdot \lambda^2}{(4\pi d)^2} \tag{1}$$

where Pr is the received power at the receiving antenna (watt), Pt is the transmitted power at the transmitting antenna (watt), Gt is the transmitting antenna's gain, Gr is the receiving antenna's gain, d is the distance between the two antennas (m) and λ is the wavelength of the radio wave in use (m).

The above equation is fulfilling the requirement in estimating the received power at the receiving antenna that receives waves directly from the transmitting antenna. However, a problem occurs as in a SAR remote sensing double hopping happens, where the transmitted waves hit an object first then reflected towards the receiving antenna. This problem is visually explained by Figure 1. This problem requires a solving approach.

Secondly, in the context of dynamic computation, there is a discretization issue, that is, that there should be an approach to produce output values at any x-y position.

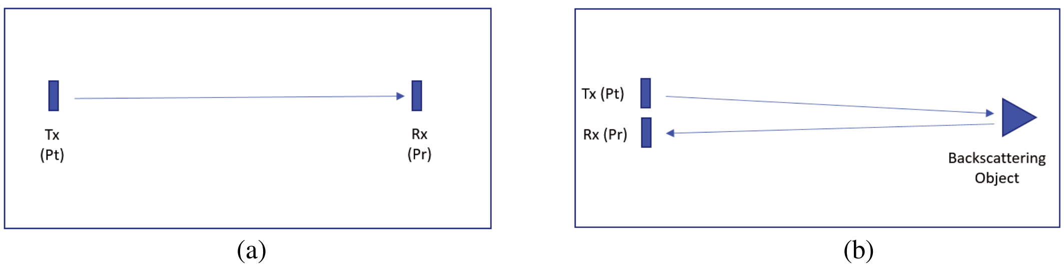


Figure 1: (a) shows a line-of sight radio wave transmission event where the Friis Formula directly applies, (b) explains the first problem (challenge) occurs in an event of SAR remote sensing; multihopping, where Friis Formula needs to be elaborated.

2.2. Proposed Solving Method and Algorithm

2.2.1. Solving the Multihopping Problem

We are proposing the solution method for the first problem as mentioned in sub-section 2.1 principally by dividing the transmission path into two legs, that are, leg1 the departing path (from Tx to object) and leg2 the returning path (from object to Rx). This method is then elaborated into the path splitting algorithm as depicted by Figure 2.

2.2.2. Solving the Discretization Problem

In general discretization is done at every computer simulation method, including ones that are addressed in [9–11]. In this particular challenge, the approach is to derive Equation (4) in a way so that Pr can be calculated dynamically, i.e., calculable for every space change (dx, dy) and time change (dt). Figure 3 visually explains the conception of the discretization applied in our study.

3. COMPUTATION MODEL

In our study the elaboration of the method is still improving. However, each conception progress was realized into our MATLAB coding. In this regard, a real case of Ground Based C-band SAR Test has been taken as the computation model.

3.1. Assigning Values to the Wave Propagation Constants and Variables

Values are assigned to the wave propagation variables in accordance to our Ground Based C-band SAR Test that has been carried out on the June 15, 2017. These values are as follows: $co = 2.9979e8\,\text{m/s}$, $f = 5.3\,\text{GHz}$, $\varepsilon_o = 8.8542e-12\,\text{F/m}$, $\mu_o = 1.2566e-6\,\text{H/m}$, transmitting power = 44 dBm (25 watt), transmitting antenna's gain = 23.42 dBi(219), receiving antenna's gain = 23.42 dBi(219), backscattering object's relative permittivity, $\varepsilon_r = 10.8$, backscattering object's

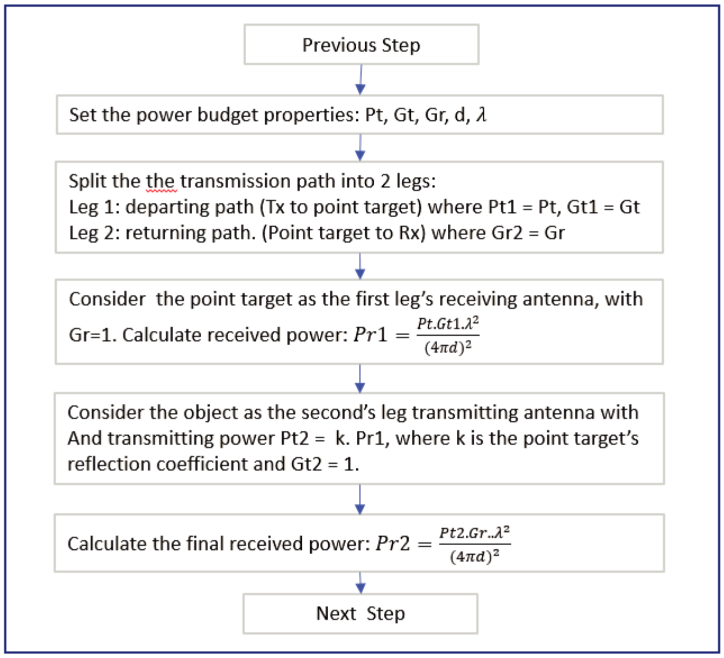


Figure 2: Proposed Path Splitting Algorithm, as a solution to the multihopping problem. The value of k shall be computed based on point target (object)'s material permittivity and surface roughness.

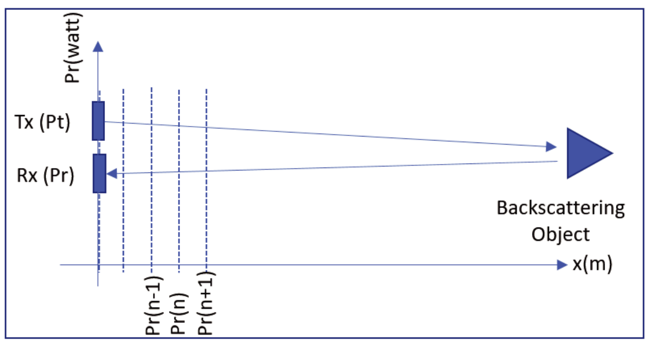


Figure 3: This explains our conception of the discretization. For simplicity here only one-dimension discretization of Pr is shown. When carrying out an FDTD computation, statically usage of Friis Formula is not applicable because $Pr(n)$ shall be computed based on $Pr(n-1)$, instead of $P(0)$ or the transmitting power (Pt).

relative permeability $\mu_r = 1$, receiver sensitivity $= -85\,\text{dBm}$ (3.16 pw). The assignment of these values into the computer program's variables and constants is depicted by Figure 4.

3.2. Confirming the Position of SAR Test Elements

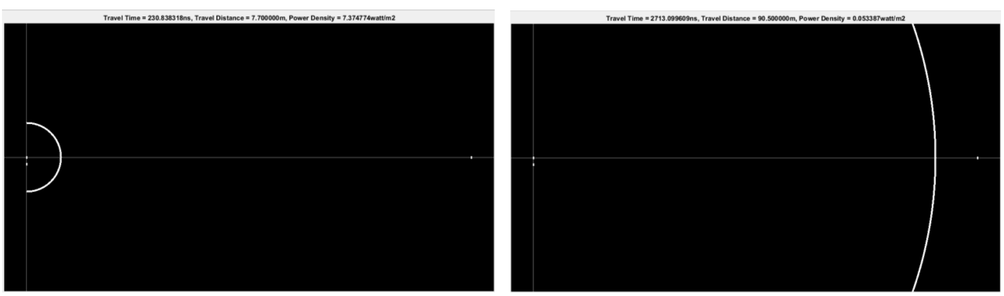
In a ground-based SAR test, the position of the SAR device (Tx/Rx), the azimuth length, the range length and the position of the backscattering object (point target) relative to the Tx/Rx is also crucial. In the MATLAB program we visualized this position setting and it is here depicted in Figure 4. The visualization of correct position of each element provided confidence in proceeding with the computation.

4. PRELIMINARY RESULT AND DISCUSSION

While this study is still on-going, some preliminary results of are here presented. Figure 5 shows the simulation states at the first leg (propagation between the Tx antenna and the corner reflector) whereas Figure 6 shows the simulation states at the second leg (propagation between the corner reflector and the Rx antenna).

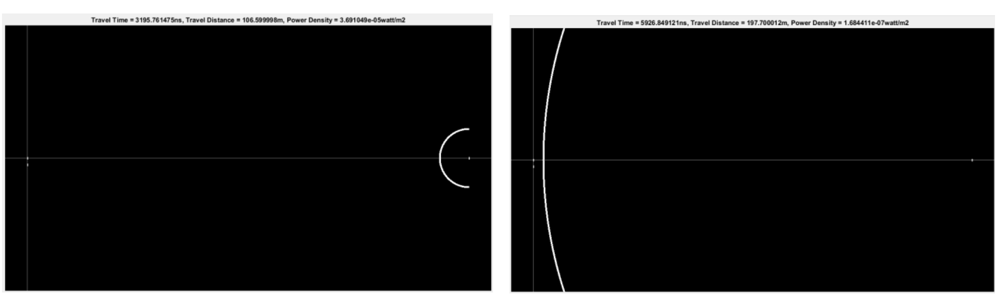
The simulation resulted in several reasonable data: from Figures 5 and 6 — even clearer from the video clip- it is seen that the value of Pr decreases with travel distance and travel time. It can be seen from Figure 6(a) that at an early time step, at the distance of 26.8 m the wave power is 15.23 dBm. It is interesting to find in Figure 7(b), the value of the final state of the simulation: the net power received by the receiving antenna is −2.13 dBm. This indicates that the study has been able to show the right trend of the data. However, the accuracy of these numerical values is subject to further assessment.

Figure 4: Visualization of the SAR test elements within the program. The vertical line is the azimuth line (Y-axis), the horizontal line is the range line (X-axis), the two white bars in the left side are the transmitting antenna and the receiving antenna, the white bar in the right side is the corner reflector (point target). Distance between antenna and the corner reflector is 100 m.



(a) (b)

Figure 5: This figure shows states of the simulation at two different time steps of the first leg: (a) is at an early time step, that is, a while after the wave departed from the Tx antenna, (b) is at a late time step, that is, when the wave is approaching the corner reflector.



(a) (b)

Figure 6: This figure shows states of the simulation at two different time steps of the second leg: (a) is at an early time step, that is, a short time after reflection by the corner reflector, (b) is at a the final time step, that is, when the wave is about to reach the receiving antenna.

5. CONCLUSION

Out of this study, it can be recognized that (i) in a computer simulation on wave propagation dynamic calculation of wave power is possible, (ii) the dynamic calculation of the wave power can be done using the method and algorithm proposed in this paper, (iii) by doing so, estimating the received power at the receiver antenna of a ground-based SAR is possible. However, it is to be noticed that this study is still on-going, thus will probably result in further updates and correction(s) in the future.

ACKNOWLEDGMENT

We would like to convey our gratitude to Mitsubishi Corporation International Student Scholarship for their funding support to the study, as well as the Ministry of Research, Technology and Higher Education of the Republic of Indonesia (Kemenristekdikti) for their support to the research.

REFERENCES

1. Nagatani, Y., et al., "Numerical and experimental study on the wave attenuation in bone-FDTD simulation of ultrasound propagation in cancellous bone," *Ultrasonics*, Vol. 48, 607–612, 2008.
2. Lim, H. B., et al., "Confocal microwave imaging for breast cancer detection: Delay-multiply-and-sum image reconstruction algorithm," *IEEE Transactions on Biomedical Engineering*, Vol. 55, No. 6, 1697, June 2008.
3. Hagness, S. C., et al., "Two-dimensional FDTD analysis of a pulsed microwave confocal system for breast cancer detection: Fixed-focus and antenna-array sensors," *IEEE Transactions on Biomedical Engineering*, Vol. 45, No. 12, December 1998
4. Jokovic, V., et al., "FDTD simulation of microwave heating of variable feed," *Minerals Engineering*, Vol. 59, 12–16, 2014.
5. Qakir, M., G. Qakir, and L. Sevgi, "A two-dimensional FDTD-based virtual visualization tool for metamaterial-wave interaction," *IEEE Antennas and Propagation Magazine*, Vol. 50, No. 3, 166–175, June 2008
6. Dowd, B. and R. E. Diaz, "FDTD simulation of very large domains applied to radar propagation over the ocean," *IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, San Diego, 2017.
7. Razi, P., et al., "3D land mapping and land deformation monitoring using persistent scatterer interferometry (PSI) ALOS PALSAR: Validated by geodetic GPS and UAV," *IEEE Access*, Vol. 6, 12395–12404, February 2018.
8. Friis, H. T., "A note on a simple transmission formula," *Proc. IRE*, 254–256, 1946.
9. Inan, U. S. and R. A. Marshall, *Numerical Electromagnetics: The FDTD Method*, Cambridge University Press, New York, 2011.
10. Yu, W., et al., *Electromagnetic Simulation Techniques Based on the FDTD Method*, John Wiley & Sons, New Jersey, 2009.
11. Taflove, A. and S. C. Hagness, *Computational Electrodynamics: The Finite-Difference Time-Domain Method*, 3rd Edition, Artech House, Norwood, MA, 2005.