Chapter 1. Electromagnetic Wave Theory and Applications

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1.1 Inversion of Sea Ice Parameters

Sponsor

U.S. Navy - Office of Naval Research
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Project Staff

Professor Jin Au Kong, Dr. Kung Hau Ding, Dr. Y. Eric Yang, Arthur K. Jordan, Kevin O'Neill, Michael Tsuk, Jerome J. Ackerson, Yin-Chun (Andrew) Kao, Kulapant Pimsamarn, Makkalon Em, Shih-En Shih, Nayon Tomsio, Chen-Pang Yeang, Yan Zhang, Henning Braunisch

The goal of this research is to investigate the dependence of active and passive microwave measurements on sea ice parameters and to develop practical reconstruction methods for retrieving sea ice parameters using remote electromagnetic measurements. In this project, we have developed theoretical forward scattering models for sea ice under various environmental conditions with varying morphological structures and physical properties. The scattering model has taken into account the combined volume and surface scattering effects for accurate prediction of microwave signatures. Comparison between model results and experimental measurements with ground truth has been carried out to validate the scattering model. The analysis has confirmed the volume scattering contribution, due to sea ice inhomogeneities like brine and air bubble inclusions, to the radar response of sea ice. The coupled volume and surface scattering mechanism is important in the understanding of sea ice electromagnetic properties and the reconstruction of sea ice parameters.

Frost flowers have become important in the study of sea ice remote sensing owing to their role in the observed enhancement of radar backscatter from thin sea ice. Frost flowers are saline ice crystals growing on the surface of young sea ice. The flowers are accompanied by slush patches underneath ice crystals. In this work, we have developed an electromagnetic backscattering model of thin saline ice covered with frost flowers. The formation process of frost flowers during the growth of ice is simulated using a

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random walk model. Geometric parameters, such as coverage and dimension, and physical parameters, such as salinity and temperature, of frost flower slush patches are incorporated into different simulated stages in accordance with the measured characterization data. Backscattered field is then calculated from the simulated scenario by solving a volume integral equation based on an approximated internal field. The induced internal field within the slush layer is approximated by adopting a layered-medium model which takes into account the salinity profile of saline ice. The backscattering coefficients are obtained by averaging over many simulated realizations. This Monte Carlo scattering model is applied to interpret the temporal variation of the C-band polarimetric signatures observed in CRRELEX 95 indoor experiment. The model results agree with the observed C-band radar backscatter which shows an increasing trend with the coverage of frost flowers on ice. Also, the developed model explains the backscatter minimum occurred in the early stage of frost flower growth which coincided with an abrupt change in the saline ice surface salinity.

A novel electromagnetic inverse scattering theory using time-series backscatter measurements has been developed to reconstruct the evolution of thin saline ice thickness. This inverse scattering algorithm is based on a dynamic electromagnetic scattering model of saline ice and the time-series active remote sensing measurements. The direct scattering model consists of a saline ice physical model describing the dynamic variations of ice characteristics under varying environmental conditions coupled with an electromagnetic scattering model accounting for wave propagation and scattering in a multilayer random medium with rough interfaces.

Interpretations of CRRELEX 93 (under a constant temperature condition) and CRRELEX 94 (under diurnal thermal cycling effects) radar results using this dynamic-electromagnetic scattering model have been demonstrated. The inversion algorithm using time-series data is formulated based on this direct scattering model and a parametric estimation scheme which minimizes the difference between backscatter data and model responses subject to physical constraints imposed by sea ice growth physics. This inversion algorithm is then applied to reconstruct the growth of thin saline ice by using the C-band polarimetric radar sequential measurements from the CRRELEX 93 and CRRELEX 94 experiments. The inversion results show good agreement with the ground truth measurements. The demonstrated accurate thickness retrieval suggests the potential usage of this algorithm for the satellite remote sensing of sea ice.

1.2 Study of the Effects of Radio Interference on ILS

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Project Staff

Professor Jin Au Kong, Dr. Y. Eric Yang, Igor Balk, Chen-Pang Yeang, Yan Zhang

Category III ILS autoland systems are designed to meet not only the accuracy limits but also stringent requirements in reliability measures such as availability, continuity of service, and integrity failure rates. Ideally, clean ILS signals must be maintained in the vicinity of airports where automatic landing mode will be engaged. In reality, interference from other RF sources might be possible because the frequency bands the ILS components operate are heavily populated with high-power emitters. ILS autolanding system integrity and continuity risk under various RF interference conditions is analyzed in this study.

Generic simulation models of the autoland system are developed for airline transports with varying weights and different extent of inertial smoothing in the control system. The autoland model is combined with the ILS receiver response model and wind disturbance model to simulate the final approach process. Monte Carlo simulations over hundreds of landings are conducted to assess the total system risk. The continuity risk is defined to be the probability of CDI current exceeding 20 microamps during the final 30 seconds, a condition which normally causes the autoland system to "disconnect." The integrity risk is defined by the probability of key system performance measures exceeding certain boundaries at the touch down point even when there is no disconnect, i.e., without detectable alarms.

The key measures defining a successful landing include aircraft lateral displacement, banking angle, and sideslip rate. We found from the simulation that continuity risk appears to dominate integrity risk and that present standards of RF interference immunity for ILS receivers provide a sufficient margin to control the continuity risk. The study also shows that when certain conditions are met, control systems with inertial smoothing have lower integrity risk than those without it. The simulation programs developed in this project are also used to investigate various proposed schemes to extend the service life of existing ILS systems before the satellite-based system took over within the next 20 years.

1.3 Development of Atmospheric Attentuation Model

Sponsor

California Institute of Technology
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Project Staff

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The emitted electromagnetic energy from the ocean, measured as brightness temperature, depends on the ocean surface temperature and roughness. Previous studies have shown that the Stokes parameters are harmonic functions of the azimuthal angle of the observation direction. The amplitude of the harmonic variation increases as surface roughness increases. This salient feature has been applied in the passive remote sensing of ocean to retrieve the ocean surface characteristics. However, most of the previous studies of ocean remote sensing focused on the interaction between electromagnetic waves and surfaces, and the contribution from atmospheric absorption and radiation to the passive measurements are not included, which may influence the interpretation of passive data in the microwave frequency range. It is found that the harmonic variations of the Stokes parameters are strongly affected by the atmosphere, depending on the opacity of the atmosphere.

In this work, we develop an emission and scattering model to calculate the brightness temperatures of the ocean with the effects of atmosphere taken into account. The ocean surface is modeled as a one-dimensional random rough surface. The surface profile is generated by using the Monte Carlo technique. The electromagnetic wave scattering from the surface is solved based on the extended boundary condition (EBC) method. The millimeter-wave propagation model (MPM) is applied to obtain the propagation characteristics of microwaves in the atmosphere. The atmospheric parameters are specified according to the U.S. Standard Atmosphere 1976. The brightness temperatures observed above the atmosphere are obtained by solving the radiative transfer equations in which surface scattering of electromagnetic wave is imposed as a boundary condition.

Simulations are carried out to interpret the 1995 NASA WINDRAD data set. The effects of frequency, polarization, observation angle, and atmospheric conditions are studied. The simulation results indicate that in the atmosphere Th and Tv are higher while the third Stokes parameter U is lower than than the values in free space. The atmospheric contribution is shown to be the largest at 22 GHz among four frequencies 17 GHz, 19.35 GHz, 22 GHz and 37 GHz. The more humid or warmer air has more atmospheric contribution. In addition to the numerical scheme, we also derive an approximation method to estimate the correction of the atmospheric effect on the brightness temperatures without directly solving the radiative transfer equations. The sensitivities of both numerical and approximated schemes are compared at different nadir angles, atmospheric parameters, surface roughness, and frequencies.

1.4 SIR-C Polarimetric Radar Image Simulation and Interpretation

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This project investigates the use of spaceborne polarimetric radar measurements for monitoring, mapping, and retrieving the aboveground vegetation biomass. Fully polarimetric radar data obtained from the SIR-C/XSAR missions over the Landes Forest in Southwestern France have been detailedly analyzed. In the investigation of the application of SIR-C data to vegetated terrain classification and biomass inversion, the measured backscattering coefficients, the derived complex correlation coefficient of HH and VV polarization as well as the ratio between cross- and co-polarization are fully utilized. A validated pine forest scattering model, which is based on the radiative transfer theory with the specific branching structure of the pine tree taken into account, is used to interpret the SIR-C/XSAR polarimetric backscattering measurements from the Landes forest. From the analysis of measured data and the model results, the cross-polarization backscattering coefficients at L-band and the correlation between HH and VV back-scattering returns at both L- and C-band are found to be most useful for the biomass retrieval. Bayesian classifications using data with known ground truth and with theoretical simulation are applied to classify the forest for biomass up to 50 tons per hectare with the available data. With the use of the pine forest scattering model, biomass inversion has been shown to be feasible over a wider biomass range (up to 100 tons per hectare) for angles of incidence around 45 degrees. In addition to the analysis of SIR-C/XSAR data, we have refined our forest scattering model by taking into account the double scattering mechanism between trunk and branches which shows more effects on the cross-polarized backscattering return.

Recently, there have been some pilot studies that use ERS-1 data to estimate rice crop acreage and monitor rice growth at several places in Asia. Through this project, we also develop a theoretical scattering model for the rice canopy to analyze the temporal variation of radar backscatters from different rice growth stages observed by ERS-1. The scattering model takes into account the cluster structure of rice plants, a flooded ground surface, and coherent wave interactions between scattering components. The effects of attenuation on the coherent wave caused by inhomogeneities are taken into account using the Foldy's approximation. The Monte Carlo simulation algorithm is employed to compute the scattering return from the rice field. The simulated backscattering results at different growth stages are in good agreement with the ERS-1 data. Simulations are also performed to explain some phenomena observed from the JERS-1 data and SIR-C data. A similar model is further developed for the sunflower field with rough soil ground. The scattering from rough ground surface is obtained using Kirchhoff approximation. The simulated backscatters at different growth stages of the sunflower are in good agreement with the experimental data obtained from the Montespertoli test site in Italy during the airborne Remote Sensing Campaign Mac-Europe 91. The model is then utilized in the inversion of sunflower biomass with the neural network technique.

1.5 Polarimetric Passive Remote Sensing

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In the microwave remote sensing of ocean surface, the use of polarimetric passive techniques has shown potential for enhancing the retrieval of wind speed and directions. The recent theoretical and experimental research activities have concentrated on studying the polarimetric thermal emission from an anisotropic ocean surface with the assumption of a smoothly varying surface profile. However, this assumption becomes invalid under high wind conditions, and the presence of breaking water waves, white caps and foam patches will significantly affect the polarimetric brightness temperatures of the open ocean surface.

The principal goal of this project is to obtain a better understanding of how the third Stokes brightness parameter, U, is related to ocean wind direction. This brightness parameter, which is not measured in conventional passive remote sensing, has recently been shown to respond to the azimuthal anisotropy of the observed medium and thus should give information on ocean wind direction. This work presents a theoretical study on the polarimetric thermal emission from a foam covered ocean surface based on the radiative transfer approach.

In this model, the composite volume and rough surface scattering effects between the ocean surface and foam cover are taken into account. For the foam layer, the water droplets are represented by dielectric spherical particles overlying the wind-driven ocean surface. The ocean surface is modeled as a random rough surface characterized by an empirical power spectrum density. The small perturbation method is used for calculating the scattering from the ocean surface, where the bistatic scattering is calculated up to the second order. The radiative transfer equations with rough interface are solved using the iterative technique. Theoretical predictions of this model are compared with the empirical expressions for foam layer emissivity and the 1995 NASA WINDRAD measurement data. The results indicate the important contribution of the volume scattering of foam layer to the brightness temperatures Th and Tv and the effects of anisotropic ocean surface under high wind conditions on the third Stokes parameter U.

1.6 Analytic and Monte Carlo Studies on Electromagnetic Interactions with Nonspherical Dense Media

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A dense medium is a medium in which the particles occupy an appreciable fractional volume. To study the scattering properties of such a medium, analytic multiple scattering theory relies on approximation such as the quasicrystalline approximation (QCA), and the quasicrystalline approximation with coherent potential (QCA-CP). However, with the advent of modern computers, it becomes applicable to numerically solve Maxwell's equations for such dense media problem. Such simulations can be done by packing several thousand particles randomly in a box and then solving Maxwell's equations. The simulations are performed over many samples (realizations), and the scattering results are averaged over these realizations. The results give information about the collective scattering effects of many particles packed together.

Such a simulation has several advantages: (1) it can yield results that can be compared with multiple scattering analytic approximations; (2) it can give complete scattering results such as extinction rates, absorption rates, phase functions of co-polarization and cross-polarization as well as the statistics of such scattering properties; (3) it can give results that are too complicated to treat analytically, such as cases of very high density of particles, sticky particles, and non-spherical particles.

In this work, we perform Monte Carlo simulations of electromagnetic waves scattering from random media with non-spherical particles. Scattering by non-spherical particles has interesting results, particularly the polarimetric dependence of scattering. The multiple scattering equations are formulated through the volume integral equation and solved numerically. The method of moments is used with choices of basis functions that are appropriate for spheroids. A shuffling process is used to generate the positions of densely packed spheroids. Both cases of aligned orientations and random orientations are considered. In the course of shuffling, we have to check whether any two spheroids overlap. Such checking is facilitated by the use of contact functions. Numerical simulations are performed for the extinction rates and the phase matrices using several thousands of spheroids. Salient features of numerical results indicate that: (1) the extinction rates of densely packed small spheroids are smaller than those of independent scattering; (2) for aligned spheroids, the extinction rates are polarization dependent, while for completely random orientation, the extinction rates are polarization independent; and (3) the copolarized part of the phase matrix is smaller than that of independent scattering while the depolarized part is larger than that of independent scattering. This indicates that the ratio of cross-polarization to co-polarization is significantly higher than that of independent scattering.

1.7 Analysis of Electromagnetic Interaction with Ships on the Ocean

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Project Staff

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Far-field electromagnetic interaction models for canonical shapes representing parts of ship bodies, such as flat plate and circular cylinders on the ocean surface is investigated. An iterative solution for scattering from a conducting object above a randomly rough dielectric surface has been formulated using Huygens' principle. This model incorporates analytical techniques, Small Perturbation Method (SPM) and Kirchhoff Approximation (KA) for rough surface scattering and Physical Optics (PO) for scattering from the conducting body, to examine the direct and multiple scattering mechanisms for the coupled system. We first consider scattered field from the conducting body and the rough surface alone. The secondary scattering components are evaluated by projecting the primary scattering fields to the discrete object and rough surface as additional sources. Using the iterative technique, we can evaluate the spread of scattering energy associated with different surface roughness. The main lobe in bistatic return is seen to decrease with increasing roughness, whereas some sidelobes pick up strengths. This spread is expected, as the scattered energy is directed away from the specular direction. A hybrid method of moments (MoM)/SPM technique has been developed to overcome the difficulties that purely MoM encountered when it is applied to full three dimensional problems. Using layered dyadic Green's function formulation, it is necessary to solve only unknown current distribution on the discrete conducting object but not that on the rough surface, thus saving significant amount of computer memory and CPU time. This has been demonstrated in the configuration with infinitely thin vertical plate slightly above the rough surface.

1.8 Electromagnetic Waves in Complex Media

Sponsor

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Project Staff

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This research is focused on theoretical studies of electromagnetic phenomena in complex media that will lead to applications in the modeling and analysis of realistic electronic systems. We concentrate our efforts on those characteristics that have major impacts on system behavior, in particular on electromagnetic interaction with detailed geometrical features and material properties.

Dielectric waveguides are commonly used as interconnects in millimeter-wave and submillimeter wave integrated circuit technologies. These interconnects contain discontinuities such as bends that affect the mode propagation through the waveguide. Since propagating modes in this type of structure are characterized by complex field distributions that do not have exact analytic solutions, a full three-dimensional finite difference time domain (FDTD) implementation is used to investigate the effects of rib waveguide discontinuities on the fundamental mode's propagation.

Because of the open nature of the dielectric rib waveguide, analyzing the discontinuities with the FDTD method requires absorbing boundary conditions that simulate open space. In this work, Berenger's perfectly matched layer (PML) is used to terminate the computational domain. Matching these multiple dielectric layers requires special consideration. We have discovered that it is necessary to provide equal dampening (within adjacent dielectric layers) in the direction normal to the PML interface instead of matching the reflection coefficient between each dielectric/PML interface.

1.9 Research on SAR Simulation Model

Sponsor

Mitsubishi Corporation

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In spaceborne synthetic aperture radar (SAR) interferometry, the terrain elevation information is obtained from the phase difference of two SAR images gathered by the same sensor in repeated passes. In order to compare various processing methods systematically, we developed a simulation model called EMSARS based on physical principle of electromagnetic scattering. GIS database—including digital elevation map (DEM) and feature map—is used to create synthesized SAR images.

The real SAR simulation involves calculation of the received field for each time step and frequency component, a very time-consuming process. We choose instead to start from the simulated range of compressed data, in which the scattered field for each azimuthal step is calculated by summing up scattering field from individual cells that are within the specified azimuthal beamwidth and range resolution. K-distribution statistics are used to simulate the speckle inherent to the radar data. The scattering fields obtained from two repeat passes are combined to form the interferogram. The Doppler part of the commonly used range-Doppler algorithm is used to synthesize images under various misalignment conditions.

1.10 Research on SAR Interferometry

Sponsor

Mitsubishi Corporation

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In spaceborne synthetic aperture radar (SAR) interferometry, the terrain elevation information is obtained from the phase difference of two SAR images gathered by the same sensor in repeated passes. Among the factors crucial to the accuracy of altitude mapping are the registration of complex SAR images and the phase unwrapping processes. In the processing of interferometric SAR (InSAR) data, a number of experiences have been reported in the literature and various methods about the interferometric SAR image registration and phase unwrapping are available. A phase unwrapping study on both simulated and real SAR image data is conducted. Both the hybrid weighted least squares and the optimum branch cut methods offered essentially the same error performance when applied to both simulated SAR interferograms with additive noise and real ERS-1 interferograms. These methods consistently showed improvement over the straight least squares and coherence weighted least squares methods.

The global optimum branch cut method is appropriate when there are not that many residues; however, the local optimum provides near identical results in far less time. The branch cut method is more likely to produce local errors as shown by the symmetrical error histograms, and the hybrid weighted least squares method produces a fairly symmetrical histogram especially when compared to the straight least squares and coherence weighted least squares methods. In other words, using a weighting scheme greatly reduces the global error introduced by the least squares method. In fact, the residue mask most closely approaches the desirable local error distribution of the branch cut method. The results show that the residue weighting scheme (or hybrid method) offers superior performance over the coherence and modified coherence weighting schemes.

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1.1 Inversion of Sea Ice Parameters

Sponsor

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Project Staff

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The goal of this research is to investigate the dependence of active and passive microwave measurements on sea ice parameters and to develop practical reconstruction methods for retrieving sea ice parameters using remote electromagnetic measurements. In this project, we have developed theoretical forward scattering models for sea ice under various environmental conditions with varying morphological structures and physical properties. The scattering model has taken into account the combined volume and surface scattering effects for accurate prediction of microwave signatures. Comparison between model results and experimental measurements with ground truth has been carried out to validate the scattering model. The analysis has confirmed the volume scattering contribution, due to sea ice inhomogeneities like brine and air bubble inclusions, to the radar response of sea ice. The coupled volume and surface scattering mechanism is important in the understanding of sea ice electromagnetic properties and the reconstruction of sea ice parameters.

Frost flowers have become important in the study of sea ice remote sensing owing to their role in the observed enhancement of radar backscatter from thin sea ice. Frost flowers are saline ice crystals growing on the surface of young sea ice. The flowers are accompanied by slush patches underneath ice crystals. In this work, we have developed an electromagnetic backscattering model of thin saline ice covered with frost flowers. The formation process of frost flowers during the growth of ice is simulated using a

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random walk model. Geometric parameters, such as coverage and dimension, and physical parameters, such as salinity and temperature, of frost flower slush patches are incorporated into different simulated stages in accordance with the measured characterization data. Backscattered field is then calculated from the simulated scenario by solving a volume integral equation based on an approximated internal field. The induced internal field within the slush layer is approximated by adopting a layered-medium model which takes into account the salinity profile of saline ice. The backscattering coefficients are obtained by averaging over many simulated realizations. This Monte Carlo scattering model is applied to interpret the temporal variation of the C-band polarimetric signatures observed in CRRELEX 95 indoor experiment. The model results agree with the observed C-band radar backscatter which shows an increasing trend with the coverage of frost flowers on ice. Also, the developed model explains the backscatter minimum occurred in the early stage of frost flower growth which coincided with an abrupt change in the saline ice surface salinity.

A novel electromagnetic inverse scattering theory using time-series backscatter measurements has been developed to reconstruct the evolution of thin saline ice thickness. This inverse scattering algorithm is based on a dynamic electromagnetic scattering model of saline ice and the time-series active remote sensing measurements. The direct scattering model consists of a saline ice physical model describing the dynamic variations of ice characteristics under varying environmental conditions coupled with an electromagnetic scattering model accounting for wave propagation and scattering in a multilayer random medium with rough interfaces.

Interpretations of CRRELEX 93 (under a constant temperature condition) and CRRELEX 94 (under diurnal thermal cycling effects) radar results using this dynamic-electromagnetic scattering model have been demonstrated. The inversion algorithm using time-series data is formulated based on this direct scattering model and a parametric estimation scheme which minimizes the difference between backscatter data and model responses subject to physical constraints imposed by sea ice growth physics. This inversion algorithm is then applied to reconstruct the growth of thin saline ice by using the C-band polarimetric radar sequential measurements from the CRRELEX 93 and CRRELEX 94 experiments. The inversion results show good agreement with the ground truth measurements. The demonstrated accurate thickness retrieval suggests the potential usage of this algorithm for the satellite remote sensing of sea ice.

1.2 Study of the Effects of Radio Interference on ILS

Sponsor

U.S. Federal Aviation Administration
Contract 94-G-007
Contract 97-G-031

Project Staff

Professor Jin Au Kong, Dr. Y. Eric Yang, Igor Balk, Chen-Pang Yeang, Yan Zhang

Category III ILS autoland systems are designed to meet not only the accuracy limits but also stringent requirements in reliability measures such as availability, continuity of service, and integrity failure rates. Ideally, clean ILS signals must be maintained in the vicinity of airports where automatic landing mode will be engaged. In reality, interference from other RF sources might be possible because the frequency bands the ILS components operate are heavily populated with high-power emitters. ILS autolanding system integrity and continuity risk under various RF interference conditions is analyzed in this study.

Generic simulation models of the autoland system are developed for airline transports with varying weights and different extent of inertial smoothing in the control system. The autoland model is combined with the ILS receiver response model and wind disturbance model to simulate the final approach process. Monte Carlo simulations over hundreds of landings are conducted to assess the total system risk. The continuity risk is defined to be the probability of CDI current exceeding 20 microamps during the final 30 seconds, a condition which normally causes the autoland system to "disconnect." The integrity risk is defined by the probability of key system performance measures exceeding certain boundaries at the touch down point even when there is no disconnect, i.e., without detectable alarms.

The key measures defining a successful landing include aircraft lateral displacement, banking angle, and sideslip rate. We found from the simulation that continuity risk appears to dominate integrity risk and that present standards of RF interference immunity for ILS receivers provide a sufficient margin to control the continuity risk. The study also shows that when certain conditions are met, control systems with inertial smoothing have lower integrity risk than those without it. The simulation programs developed in this project are also used to investigate various proposed schemes to extend the service life of existing ILS systems before the satellite-based system took over within the next 20 years.

1.3 Development of Atmospheric Attentuation Model

Sponsor

California Institute of Technology
Contract JPL 960408

Project Staff

Professor Jin Au Kong, Dr. Kung Hau Ding, Dr. Y. Eric Yang, Chen-Pang Yeang, Yan Zhang

The emitted electromagnetic energy from the ocean, measured as brightness temperature, depends on the ocean surface temperature and roughness. Previous studies have shown that the Stokes parameters are harmonic functions of the azimuthal angle of the observation direction. The amplitude of the harmonic variation increases as surface roughness increases. This salient feature has been applied in the passive remote sensing of ocean to retrieve the ocean surface characteristics. However, most of the previous studies of ocean remote sensing focused on the interaction between electromagnetic waves and surfaces, and the contribution from atmospheric absorption and radiation to the passive measurements are not included, which may influence the interpretation of passive data in the microwave frequency range. It is found that the harmonic variations of the Stokes parameters are strongly affected by the atmosphere, depending on the opacity of the atmosphere.

In this work, we develop an emission and scattering model to calculate the brightness temperatures of the ocean with the effects of atmosphere taken into account. The ocean surface is modeled as a one-dimensional random rough surface. The surface profile is generated by using the Monte Carlo technique. The electromagnetic wave scattering from the surface is solved based on the extended boundary condition (EBC) method. The millimeter-wave propagation model (MPM) is applied to obtain the propagation characteristics of microwaves in the atmosphere. The atmospheric parameters are specified according to the U.S. Standard Atmosphere 1976. The brightness temperatures observed above the atmosphere are obtained by solving the radiative transfer equations in which surface scattering of electromagnetic wave is imposed as a boundary condition.

Simulations are carried out to interpret the 1995 NASA WINDRAD data set. The effects of frequency, polarization, observation angle, and atmospheric conditions are studied. The simulation results indicate that in the atmosphere Th and Tv are higher while the third Stokes parameter U is lower than than the values in free space. The atmospheric contribution is shown to be the largest at 22 GHz among four frequencies 17 GHz, 19.35 GHz, 22 GHz and 37 GHz. The more humid or warmer air has more atmospheric contribution. In addition to the numerical scheme, we also derive an approximation method to estimate the correction of the atmospheric effect on the brightness temperatures without directly solving the radiative transfer equations. The sensitivities of both numerical and approximated schemes are compared at different nadir angles, atmospheric parameters, surface roughness, and frequencies.

1.4 SIR-C Polarimetric Radar Image Simulation and Interpretation

Sponsor

National Aeronautics and Space Administration
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Project Staff

Professor Jin Au Kong, Dr. Kung Hau Ding, Dr. Y. Eric Yang, Shih-En Shih, Vincent Thomassier, Li-Fang Wang, Chen-Pang Yeang, Yan Zhang

This project investigates the use of spaceborne polarimetric radar measurements for monitoring, mapping, and retrieving the aboveground vegetation biomass. Fully polarimetric radar data obtained from the SIR-C/XSAR missions over the Landes Forest in Southwestern France have been detailedly analyzed. In the investigation of the application of SIR-C data to vegetated terrain classification and biomass inversion, the measured backscattering coefficients, the derived complex correlation coefficient of HH and VV polarization as well as the ratio between cross- and co-polarization are fully utilized. A validated pine forest scattering model, which is based on the radiative transfer theory with the specific branching structure of the pine tree taken into account, is used to interpret the SIR-C/XSAR polarimetric backscattering measurements from the Landes forest. From the analysis of measured data and the model results, the cross-polarization backscattering coefficients at L-band and the correlation between HH and VV back-scattering returns at both L- and C-band are found to be most useful for the biomass retrieval. Bayesian classifications using data with known ground truth and with theoretical simulation are applied to classify the forest for biomass up to 50 tons per hectare with the available data. With the use of the pine forest scattering model, biomass inversion has been shown to be feasible over a wider biomass range (up to 100 tons per hectare) for angles of incidence around 45 degrees. In addition to the analysis of SIR-C/XSAR data, we have refined our forest scattering model by taking into account the double scattering mechanism between trunk and branches which shows more effects on the cross-polarized backscattering return.

Recently, there have been some pilot studies that use ERS-1 data to estimate rice crop acreage and monitor rice growth at several places in Asia. Through this project, we also develop a theoretical scattering model for the rice canopy to analyze the temporal variation of radar backscatters from different rice growth stages observed by ERS-1. The scattering model takes into account the cluster structure of rice plants, a flooded ground surface, and coherent wave interactions between scattering components. The effects of attenuation on the coherent wave caused by inhomogeneities are taken into account using the Foldy's approximation. The Monte Carlo simulation algorithm is employed to compute the scattering return from the rice field. The simulated backscattering results at different growth stages are in good agreement with the ERS-1 data. Simulations are also performed to explain some phenomena observed from the JERS-1 data and SIR-C data. A similar model is further developed for the sunflower field with rough soil ground. The scattering from rough ground surface is obtained using Kirchhoff approximation. The simulated backscatters at different growth stages of the sunflower are in good agreement with the experimental data obtained from the Montespertoli test site in Italy during the airborne Remote Sensing Campaign Mac-Europe 91. The model is then utilized in the inversion of sunflower biomass with the neural network technique.

1.5 Polarimetric Passive Remote Sensing

Sponsor

U.S. Navy - Office of Naval Research
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Project Staff

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In the microwave remote sensing of ocean surface, the use of polarimetric passive techniques has shown potential for enhancing the retrieval of wind speed and directions. The recent theoretical and experimental research activities have concentrated on studying the polarimetric thermal emission from an anisotropic ocean surface with the assumption of a smoothly varying surface profile. However, this assumption becomes invalid under high wind conditions, and the presence of breaking water waves, white caps and foam patches will significantly affect the polarimetric brightness temperatures of the open ocean surface.

The principal goal of this project is to obtain a better understanding of how the third Stokes brightness parameter, U, is related to ocean wind direction. This brightness parameter, which is not measured in conventional passive remote sensing, has recently been shown to respond to the azimuthal anisotropy of the observed medium and thus should give information on ocean wind direction. This work presents a theoretical study on the polarimetric thermal emission from a foam covered ocean surface based on the radiative transfer approach.

In this model, the composite volume and rough surface scattering effects between the ocean surface and foam cover are taken into account. For the foam layer, the water droplets are represented by dielectric spherical particles overlying the wind-driven ocean surface. The ocean surface is modeled as a random rough surface characterized by an empirical power spectrum density. The small perturbation method is used for calculating the scattering from the ocean surface, where the bistatic scattering is calculated up to the second order. The radiative transfer equations with rough interface are solved using the iterative technique. Theoretical predictions of this model are compared with the empirical expressions for foam layer emissivity and the 1995 NASA WINDRAD measurement data. The results indicate the important contribution of the volume scattering of foam layer to the brightness temperatures Th and Tv and the effects of anisotropic ocean surface under high wind conditions on the third Stokes parameter U.

1.6 Analytic and Monte Carlo Studies on Electromagnetic Interactions with Nonspherical Dense Media

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Project Staff

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A dense medium is a medium in which the particles occupy an appreciable fractional volume. To study the scattering properties of such a medium, analytic multiple scattering theory relies on approximation such as the quasicrystalline approximation (QCA), and the quasicrystalline approximation with coherent potential (QCA-CP). However, with the advent of modern computers, it becomes applicable to numerically solve Maxwell's equations for such dense media problem. Such simulations can be done by packing several thousand particles randomly in a box and then solving Maxwell's equations. The simulations are performed over many samples (realizations), and the scattering results are averaged over these realizations. The results give information about the collective scattering effects of many particles packed together.

Such a simulation has several advantages: (1) it can yield results that can be compared with multiple scattering analytic approximations; (2) it can give complete scattering results such as extinction rates, absorption rates, phase functions of co-polarization and cross-polarization as well as the statistics of such scattering properties; (3) it can give results that are too complicated to treat analytically, such as cases of very high density of particles, sticky particles, and non-spherical particles.

In this work, we perform Monte Carlo simulations of electromagnetic waves scattering from random media with non-spherical particles. Scattering by non-spherical particles has interesting results, particularly the polarimetric dependence of scattering. The multiple scattering equations are formulated through the volume integral equation and solved numerically. The method of moments is used with choices of basis functions that are appropriate for spheroids. A shuffling process is used to generate the positions of densely packed spheroids. Both cases of aligned orientations and random orientations are considered. In the course of shuffling, we have to check whether any two spheroids overlap. Such checking is facilitated by the use of contact functions. Numerical simulations are performed for the extinction rates and the phase matrices using several thousands of spheroids. Salient features of numerical results indicate that: (1) the extinction rates of densely packed small spheroids are smaller than those of independent scattering; (2) for aligned spheroids, the extinction rates are polarization dependent, while for completely random orientation, the extinction rates are polarization independent; and (3) the copolarized part of the phase matrix is smaller than that of independent scattering while the depolarized part is larger than that of independent scattering. This indicates that the ratio of cross-polarization to co-polarization is significantly higher than that of independent scattering.

1.7 Analysis of Electromagnetic Interaction with Ships on the Ocean

Sponsor

U.S. Navy - Office of Naval Research
Contract N00014-97-1-0172

Project Staff

Professor Jin Au Kong, Dr. Kung Hau Ding, Dr. Y. Eric Yang, Yan Zhang, Henning Braunisch, Chi O. Ao

Far-field electromagnetic interaction models for canonical shapes representing parts of ship bodies, such as flat plate and circular cylinders on the ocean surface is investigated. An iterative solution for scattering from a conducting object above a randomly rough dielectric surface has been formulated using Huygens' principle. This model incorporates analytical techniques, Small Perturbation Method (SPM) and Kirchhoff Approximation (KA) for rough surface scattering and Physical Optics (PO) for scattering from the conducting body, to examine the direct and multiple scattering mechanisms for the coupled system. We first consider scattered field from the conducting body and the rough surface alone. The secondary scattering components are evaluated by projecting the primary scattering fields to the discrete object and rough surface as additional sources. Using the iterative technique, we can evaluate the spread of scattering energy associated with different surface roughness. The main lobe in bistatic return is seen to decrease with increasing roughness, whereas some sidelobes pick up strengths. This spread is expected, as the scattered energy is directed away from the specular direction. A hybrid method of moments (MoM)/SPM technique has been developed to overcome the difficulties that purely MoM encountered when it is applied to full three dimensional problems. Using layered dyadic Green's function formulation, it is necessary to solve only unknown current distribution on the discrete conducting object but not that on the rough surface, thus saving significant amount of computer memory and CPU time. This has been demonstrated in the configuration with infinitely thin vertical plate slightly above the rough surface.

1.8 Electromagnetic Waves in Complex Media

Sponsor

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Project Staff

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This research is focused on theoretical studies of electromagnetic phenomena in complex media that will lead to applications in the modeling and analysis of realistic electronic systems. We concentrate our efforts on those characteristics that have major impacts on system behavior, in particular on electromagnetic interaction with detailed geometrical features and material properties.

Dielectric waveguides are commonly used as interconnects in millimeter-wave and submillimeter wave integrated circuit technologies. These interconnects contain discontinuities such as bends that affect the mode propagation through the waveguide. Since propagating modes in this type of structure are characterized by complex field distributions that do not have exact analytic solutions, a full three-dimensional finite difference time domain (FDTD) implementation is used to investigate the effects of rib waveguide discontinuities on the fundamental mode's propagation.

Because of the open nature of the dielectric rib waveguide, analyzing the discontinuities with the FDTD method requires absorbing boundary conditions that simulate open space. In this work, Berenger's perfectly matched layer (PML) is used to terminate the computational domain. Matching these multiple dielectric layers requires special consideration. We have discovered that it is necessary to provide equal dampening (within adjacent dielectric layers) in the direction normal to the PML interface instead of matching the reflection coefficient between each dielectric/PML interface.

1.9 Research on SAR Simulation Model

Sponsor

Mitsubishi Corporation

Project Staff

Professor Jin Au Kong, Dr. Kung Hau Ding, Dr. Y. Eric Yang, Shih-En Shih, Li-Fang Wang

In spaceborne synthetic aperture radar (SAR) interferometry, the terrain elevation information is obtained from the phase difference of two SAR images gathered by the same sensor in repeated passes. In order to compare various processing methods systematically, we developed a simulation model called EMSARS based on physical principle of electromagnetic scattering. GIS database—including digital elevation map (DEM) and feature map—is used to create synthesized SAR images.

The real SAR simulation involves calculation of the received field for each time step and frequency component, a very time-consuming process. We choose instead to start from the simulated range of compressed data, in which the scattered field for each azimuthal step is calculated by summing up scattering field from individual cells that are within the specified azimuthal beamwidth and range resolution. K-distribution statistics are used to simulate the speckle inherent to the radar data. The scattering fields obtained from two repeat passes are combined to form the interferogram. The Doppler part of the commonly used range-Doppler algorithm is used to synthesize images under various misalignment conditions.

1.10 Research on SAR Interferometry

Sponsor

Mitsubishi Corporation

Project Staff

Professor Jin Au Kong, Dr. Kung Hau Ding, Dr. Y. Eric Yang, Jerome J. Ackerson, Baeian Wu

In spaceborne synthetic aperture radar (SAR) interferometry, the terrain elevation information is obtained from the phase difference of two SAR images gathered by the same sensor in repeated passes. Among the factors crucial to the accuracy of altitude mapping are the registration of complex SAR images and the phase unwrapping processes. In the processing of interferometric SAR (InSAR) data, a number of experiences have been reported in the literature and various methods about the interferometric SAR image registration and phase unwrapping are available. A phase unwrapping study on both simulated and real SAR image data is conducted. Both the hybrid weighted least squares and the optimum branch cut methods offered essentially the same error performance when applied to both simulated SAR interferograms with additive noise and real ERS-1 interferograms. These methods consistently showed improvement over the straight least squares and coherence weighted least squares methods.

The global optimum branch cut method is appropriate when there are not that many residues; however, the local optimum provides near identical results in far less time. The branch cut method is more likely to produce local errors as shown by the symmetrical error histograms, and the hybrid weighted least squares method produces a fairly symmetrical histogram especially when compared to the straight least squares and coherence weighted least squares methods. In other words, using a weighting scheme greatly reduces the global error introduced by the least squares method. In fact, the residue mask most closely approaches the desirable local error distribution of the branch cut method. The results show that the residue weighting scheme (or hybrid method) offers superior performance over the coherence and modified coherence weighting schemes.

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