Imaging of Objects in random media and near rough surfaces

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Overview

1. Imaging of objects in random medium
2. Imaging of objects near rough surfaces and LGA (Low Grazing Angle) scattering
3. Image improvement techniques

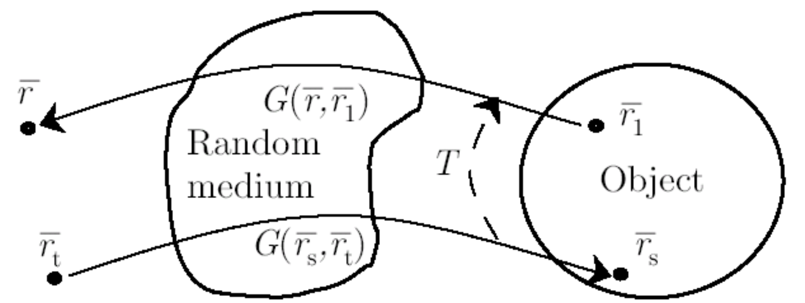
1. Imaging of objects in random medium

- General formulation based on Stochastic Green's functions
- 4^{th} order moments
- RCS of objects in random medium
- Shower curtain effects
- Backscattering enhancement

- General formulation based on Stochastic Green's functions
- Dirichlet objects in random medium
- General Formulation

$$\psi_s(\bar{r}) = -\int G(\bar{r}, \bar{r}_1) \frac{\partial \psi(\bar{r}_1)}{\partial n_1} \, \mathrm{d}S_1$$

$$\frac{\partial \psi(\bar{r}_1)}{\partial n_1} = \int T(\bar{r}_1, \bar{r}_s) \frac{\partial \psi_{in}(\bar{r}_s)}{\partial n_s} dS$$



$G(\bar{r}, \bar{r}_1)$ = Stochastic Green's function

$T(\bar{r}_1, \bar{r}_s)$ = Transition operator

$\psi_s(\bar{r})$ = Scattered field

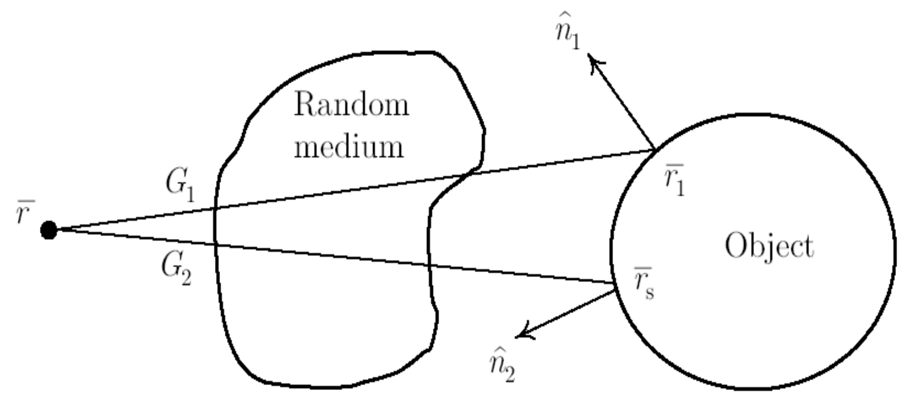
$\frac{\partial \psi(\bar{r}_1)}{\partial n_1}$ = Surface field (surface current)

- If the object surface radius of curvature is much greater than a wavelength, Kirchhoff approximation is applicable

$$T(\overline{r}_1, \overline{r}_s) = 2\delta(\overline{r}_1 - \overline{r}_s)$$

  - Surface field

$$\frac{\partial \psi(\bar{r}_1)}{\partial n_1} = 2\frac{\partial \psi_{in}(\bar{r}_1)}{\partial n_1}$$



  - Scattered power

$$\langle|\psi_s(\bar{r})|^2\rangle = 4\int\int \mathrm{d}S_1\,\mathrm{d}S_2\left\langle G_1\frac{\partial \psi_{i1}}{\partial n_1}\,G_2^*\frac{\partial \psi_{i2}^*}{\partial n_2}\right\rangle$$

- 4^{th} order moment can be expressed by second order moments using circular complex Gaussian Assumption

- Circular Complex Gaussian Assumption

$$\left\langle G_1 \frac{\partial}{\partial n_1}\psi_{i1} G_2^* \frac{\partial}{\partial n_2}\psi_{i2}^* \right\rangle = \langle G_1 G_2^* \rangle \left\langle \frac{\partial}{\partial n_1}\psi_{i1} \frac{\partial}{\partial n_2}\psi_{i2}^* \right\rangle$$

$$+ \left\langle G_1 \frac{\partial}{\partial n_2}\psi_{i2}^* \right\rangle \left\langle \frac{\partial}{\partial n_1}\psi_{i1} G_2^* \right\rangle - \langle G_1 \rangle \left\langle \frac{\partial}{\partial n_1}\psi_{i1} \right\rangle \langle G_2^* \rangle \left\langle \frac{\partial}{\partial n_2}\psi_{i2}^* \right\rangle$$

- Scattered field
- Parabolic Approximation: $\dfrac{\partial}{\partial n} = -ik\hat{s}\cdot\hat{n}_1 = -ik(\hat{z}\cdot\hat{n}_1)$

$$\left\langle |\psi_s|^2 \right\rangle = 4k^2 \int\int \Big(\mathrm{d}S_1\,\mathrm{d}S_2 \Big[\langle G_1\rangle^2 \langle G_2^*\rangle^2 + 4\langle G_1\rangle \langle G_2^*\rangle \langle G_{f1}G_{f2}^*\rangle + 2\langle G_{f1}G_{f2}^*\rangle^2 \Big] (\hat{z}\cdot\hat{n}_1)(\hat{z}\cdot\hat{n}_2) \Big)$$

Backscattering Enhancement

- RCS

$$RCS = \frac{4\pi L^2 \left\langle |\psi_s|^2 \right\rangle}{|\psi_o|^2}$$

- Ignoring correlation between incident and scattered fields

$$\left\langle |\psi_s|^2 \right\rangle = 4k^2 \int\int \Big(\mathrm{d}S_1\,\mathrm{d}S_2 \Big[\langle G_1\rangle^2 \langle G_2^*\rangle^2 + 2\langle G_1\rangle \langle G_2^*\rangle \langle G_{f1}G_{f2}^*\rangle + \langle G_{f1}G_{f2}^*\rangle^2 \Big] (\hat{z}\cdot\hat{n}_1)(\hat{z}\cdot\hat{n}_2) \Big)$$

No Backscattering Enhancement

Multiple scattering effects on RCS in random medium

- RCS of Object in Random Medium
- General Formulation – 4^{th} Order Moments
- Circular Complex Gaussian Assumptions
- Stochastic Green’s Function, Mutual Coherence Function
- Henyey-Greenstein and Gaussian Phase Function
- Shower Curtain Effects
  - Coherence length is greater if random medium is closer to transmitter
- Backscattering Enhancement
  - Correlations between forward and backward waves increase RCS

2. Imaging of objects near rough surfaces and LGA (Low Grazing Angle) scattering

- For point object (backscattering enhancement)

$$\langle E_s E_s \rangle = \langle G^2 G^{*2} \rangle = |\langle G \rangle|^2 + 4|\langle G \rangle|^2 \left\langle |G_f|^2 \right\rangle + 2\left\langle |G_f|^2 \right\rangle^2$$

- Compare with two ways without double passage effects

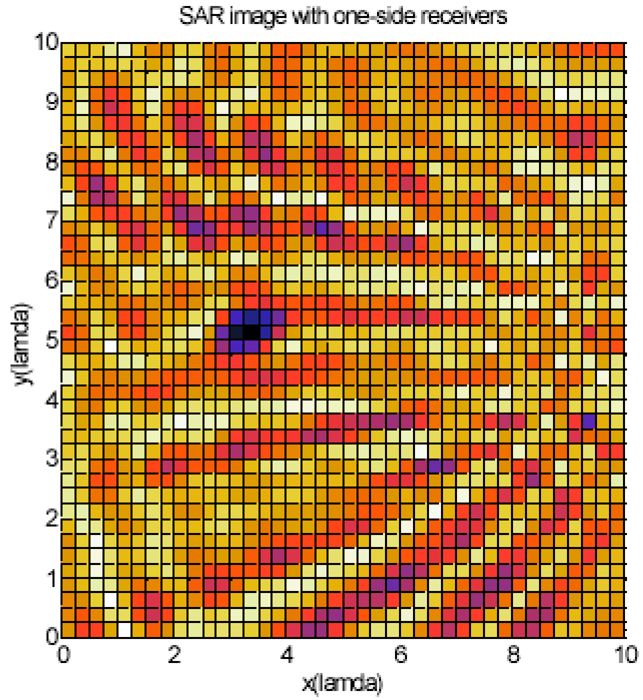
$$\langle G^2 G^{*2} \rangle = |\langle G \rangle|^2 + 2|\langle G \rangle|^2 \left\langle |G_f|^2 \right\rangle + \left\langle |G_f|^2 \right\rangle^2$$

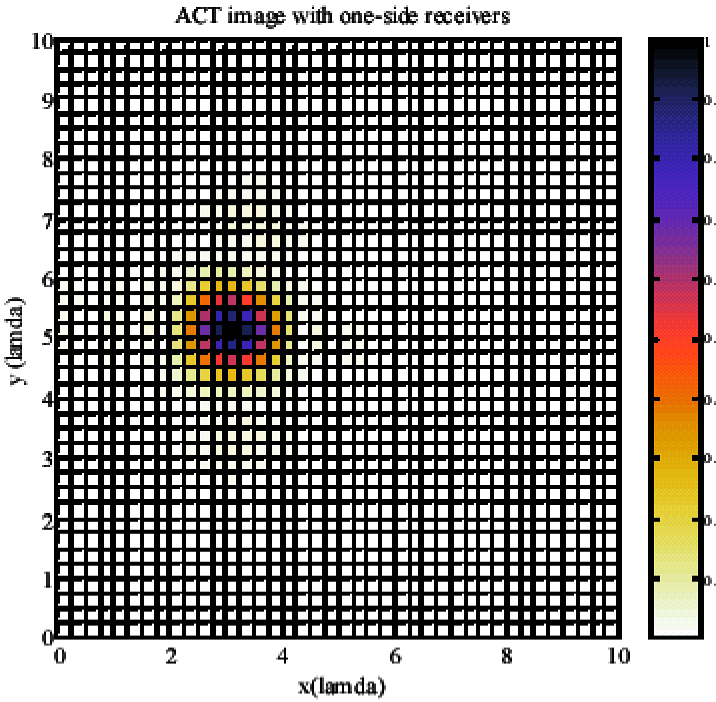
3. Image improvement techniques

- Polarization: cross-pol intensity subtraction technique (CPIS)
- Pulse – Time domain
- Photon density waves – Frequency domain
- Coherence Tomograph Imaging – Array imaging

- Coherence Tomographic Imaging (CTI)
- Array Coherence Tomography (ACT)

Array Coherence Tomography





Conclusions

- Fundamental formulations based on Stochastic Green's function
- Example of RCS and shower curtain effects and backscattering enhancement
- Objects near rough surface – Stochastic integral Equations
- Imaging improvement techniques
  - Polarization – Cross-pol intensity subtraction
  - Time domain – Pulse
  - Photon density wave imaging
  - Coherence tomographic imaging