

Generation of Synthetic SAS Data for Targets near the Seafloor: Propagation Component

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LONG-TERM GOALS

The primary objective of the proposed research is further development of an APL-UW synthetic aperture sonar simulation tool (SAS-ST) that generates sets of realistic pings suitable for SAS processing for targets near the seafloor (i.e., proud and buried targets). The propagation component will update the rough surface reverberation model to include bistatic scattering, and test and improve the propagation model for the scattered field from a target when the source and receiver are in a bistatic configuration.

OBJECTIVES

The proposed research includes three specific aims for improvements to the SAS-ST. First, reverberation due to scattering from a rough seafloor is restricted to a bistatic backscattering direction. The reverberation component will be generalized to include bistatic scattering (i.e., out-of-plane contributions). The second aim is to test and improve the propagation of an acoustic field scattered by a target when the source and receiver are in a bistatic configuration. The final goal is validation of the changes against previous experiments and against numerical simulations using alternative models. PondEx07, PondEx08, and PondEx09 provide a large set of both monostatic and bistatic SAS measurements in a controlled environment, which can be compared against the improved simulations. The Acoustic Virtual Laboratory (AVL), an APL full-wave simulation package, provides a robust test of the new components because a consistent set of environmental parameters can be used in both AVL and SAS-ST.

APPROACH

The reverberation and penetration models in SAS-ST are based on a first-order perturbation theory approximation to the scattering from and penetration through a rough surface, respectively. Originally, these models were developed independently of one another.

The reverberation model has the general form

$$p_{rev}(\vec{r}_{rcv}, t) = \frac{1}{4\pi c^2} \int_s d^2 R \frac{A_{rev}(\vec{R})h(\vec{R})p''_{src}(t-t_{rev})}{|\vec{r}_{rcv} - \vec{R}| |\vec{R} - \vec{r}_{src}|} \quad (1)$$

where the sound speed in the water is c , and the subscripts rev , rcv , and src correspond to quantities associated with reverberation, the receiver, and the source, respectively. The local surface height is $h(\mathbf{R})$, $\mathbf{R} = (x, y)$ is a location in the $z = 0$ plane, $p''(t)$ is a double time derivative of the source waveform, and $A_{rev}(\mathbf{R})$ is the following amplitude factor

$$A_{rev}(\vec{R}) = V_1(\theta_i, \theta_s) + V_2(\theta_i, \theta_s) \sin \theta_i \sin \theta_s + V_3(\theta_i, \theta_s) \cos \theta_i \cos \theta_s \quad (2)$$

with θ_i and θ_s being the incident and scattered grazing angle. The functions V_1 , V_2 , and V_3 contain material properties of the water and sediment as well as the reflection coefficients for the incident and scattered fields.

The penetration model is composed from three pieces that arose from a narrow band analysis: a refracted contribution, an evanescent contribution, and a rough surface scattered contribution. In the original construction of SAS-ST, these contributions were given in terms of a ‘‘corrected’’ baseband representation of the incident pressure, $s_{src}(t) = p_{src}(t)\exp(i\omega t)$, and have the forms

$$s_R(\vec{r}_f, t) = A_R(\vec{r}_f, \vec{r}_{src})S_{src}(t-t_R)\exp(i\omega_0 t_R) \quad (\text{refracted}) \quad (3)$$

$$s_E(\vec{r}_f, t) = A_E(\vec{r}_f, \vec{r}_{src})S_{src}(t-t_E)\exp(i\omega_0 t_E) \quad (\text{evanescent}) \quad (4)$$

$$s_1(\vec{r}_f, t) = -\frac{\rho\omega_0^2}{4\pi c^2} \int_s d^2 R \frac{A_s(\vec{R})h(\vec{R})S_{src}(t-t_s)\exp(i\omega_0 t_s)}{|\vec{r}_f - \vec{R}| |\vec{R} - \vec{r}_{src}|} \quad (\text{scattered}) \quad (5)$$

where A_R , A_E , and A_s are time-independent coefficients, which depend on material properties of the water and sediment. $S(t)$ is a slowly varying function of time; t_R , t_E , and t_s are time delays for propagating from a source location to a field point within the sediment via a refracted path, evanescent path, or rough surface scattering path; and, ω_0 is the angular carrier frequency of a broad band pulse.

WORK COMPLETED

The first-order perturbation theory models were revisited to allow bistatic scattering in the reverberation model and to write a consistent set of equations in terms of $p''(t)$. For reverberation, the result was that the amplitude factor $A_{rev}(\mathbf{R})$ in Eq. (2) becomes

$$A_{rev}(\vec{R}) = -[V_1(\theta_i, \theta_s) + V_2(\theta_i, \theta_s) \sin \theta_i \sin \theta_s + V_3(\theta_i, \theta_s) \cos \theta_i \cos \theta_s] \cos \varphi \quad (6)$$

where ϕ is the horizontal bistatic angle between the incident and scattered wave vectors (e.g., $\phi = 0^\circ$ in the forward scattering direction and $\phi = 180^\circ$ for backscatter or for vertically bistatic backscatter). The model currently implemented in SAS-ST assumes $\cos\phi = -1$; thus, giving the results shown above in Eqs. (1) and (2). In Eqs. (3) - (5), the amplitude factor $S(t)$ and phase delay factors can be collapsed into $p(t)$. So, these expressions become

$$p_R(\vec{r}_f, t) = A_R(\vec{r}_f, \vec{r}_{src}) p_{src}(t - t_R) \quad (\text{refracted}) \quad (7)$$

$$p_E(\vec{r}_f, t) = A_E(\vec{r}_f, \vec{r}_{src}) p_{src}(t - t_E) \quad (\text{evanescent}) \quad (8)$$

$$p_1(\vec{r}_f, t) = \frac{\rho}{4\pi} \int_s d^2R \frac{A_s(\vec{R}) h(\vec{R}) p_{src}''(t - t_s)}{|\vec{r}_f - \vec{R}| |\vec{R} - \vec{r}_{src}|} \quad (\text{scattered}) \quad (9)$$

where the result in Eq. (9) assumes a harmonic time dependence, and hence, $p''(t) = -\omega^2 p(t)$.

RESULTS

An emphasis was placed on the companion project, “Generation of Synthetic SAS Data for Targets near the Seafloor: Target scattering component,” at the initiation of both projects. Thus, the mathematical formulation has been reviewed, and modifications to the numerical codes are underway. Validation of the new reverberation model is scheduled for the first quarter of FY11, and the validation of the revised penetration model to follow. Both models will be compared to results obtained by AVL once the minor modifications to AVL are completed.

IMPACT/APPLICATIONS

The current version of SAS-ST has been used in comparisons with the results of Dr. Raymond Lim and Dr. Gary Sammelmann at the Naval Surface Warfare Center, Panama City Division (NSWC PCD). Good agreement was achieved between SAS-ST and Lim's T-matrix computations for a fluid-filled, steel, spherical shell under rippled sandy sediment. Furthermore, this agreement resolved an apparent inconsistency in a comparison of the T-matrix result with Sammelmann's PC-SWAT model. Sammelmann subsequently corrected PC-SWAT.

RELATED PROJECTS

Joseph Lopes of NSWC-PCD is the principle investigator on a companion program to “APL-UW Component of: Evanescent Detection of Buried Targets” and the program “Feature Sets for Classification of Underwater Targets.” The data collected by APL-UW and NSWC PCD can be used to validate modifications to the SAS-ST models.

The companion award, “Generation of Synthetic SAS Data for Targets near the Seafloor: Target Scattering Component,” seeks to improve scattering models for targets near an interface used in SAS-

ST. The research described in the present Annual Report will be merged with the target scattering component to provide an overall improvement to the fidelity of the simulated SAS data.