Simulation of Target to Clutter Ratio for Passive Phase-Conjugation Radar in Time-Varying Environments

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***Abstract*—In this paper, we propose a passive phase-conjugation scheme which has a lower system complexity than that of the active time-reversal detection scheme. Moreover, the proposed scheme does not use an additional signal processing to estimate either the target or clutter response so that the target detection can be performed very simple. MATLAB simulations are provided to show the processed result.**

I. Introduction

The passive phase-conjugation (PPC), i.e. passive time-reversal (TR) in the time domain, has been originally proposed to lower the system complexity of the conventional (active) time-reversal systems [1]. Although the TR detection systems proposed in [2], [3] provide enhanced performance for the target detection, additional signal processing techniques are required to estimate either the target or channel. Moreover, the conventional time-reversal systems require an additional transceiver platform that performs recording, time-reversal processing, and send the time-reversed signal to the original sender. In this paper, we demonstrate the PPC scheme that does not require an additional transceiver. Additional transceiver, as well as optimization or estimation process, is not used during the detection scheme. Using MATLAB simulations, the decrease of the clutter response is shown.

II. Passive Phase-Conjugation Scheme

In Fig. 1, the detection scenario for the proposed scheme is depicted. A single transceiver is located at r_0 and repeatedly transmits and receives signals with a period of Δt toward the space to be monitored. In addition, it is assumed that multiple point clutters are uniformly distributed and moving randomly in the space. Using the Green's function, the channel response for Fig. 1(a) can be obtained by

$$H_1(f,t) = \sum_{i=1}^{N} \frac{\exp\left(-j\frac{4\pi f}{c}\left|r_i(t)-r_0\right|\right)}{(4\pi)^2\left|r_i(t)-r_0\right|^2} c_i, \qquad (1)$$

where N is the number of point clutters. $r_i(t)$ and c_i are the position vector and the scattering coefficient of the i^{th} point clutter, respectively. For simplicity, ρ_i is modeled by the circularly-symmetric complex Gaussian random variable

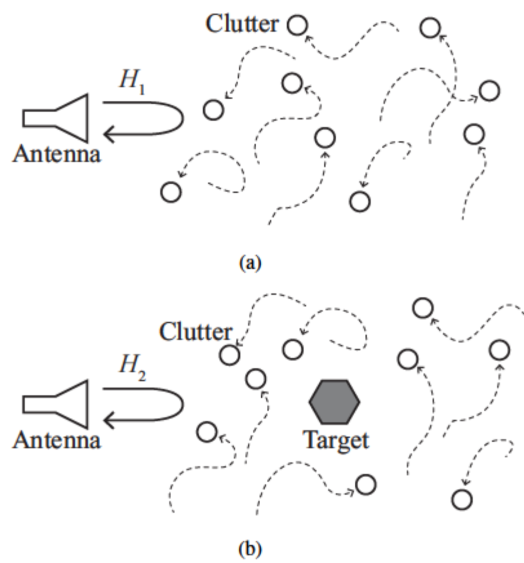

Fig. 1. Scenario of PPC detection scheme in rich scattering environment (a) before and (b) after target entering the region of interest.

with zero-mean and unit-variance. Here, we define the PPC signal as

$$S(\Delta t, t) = \frac{1}{C}\int_{f_c-\Delta f/2}^{f_c+\Delta f/2} H(f,t)H^*(f,t+\Delta t)df, \qquad (2)$$

where A^* is the complex conjugate of A, f_c is the center frequency, Δf is the bandwidth, and C is the normalizing factor given by

$$C = \int_{f_c-\Delta f/2}^{f_c+\Delta f/2} \left|H(f,t)\right|^2 df. \qquad (3)$$

Since (1) consists of only noise-like clutter responses, if (1) is applied to (2) and let $\Delta t = T$, where $T \gg 1$, (2) becomes

$$S(T,t) = \epsilon, \qquad (4)$$

where ϵ is a mean-zero noise-like random number generated by the clutters.

Now, as shown in Fig. 1(b), assume that the target locates in the space at $\boldsymbol{r}_t$. Then, the transceiver measures the channel response H_2 given by

$$H_2(f,t) = H_1(f,t) + \frac{\exp\left(-j\frac{4\pi f}{c}\left|\boldsymbol{r}_t - \boldsymbol{r}_0\right|\right)}{(4\pi)^2\left|\boldsymbol{r}_t - \boldsymbol{r}_0\right|^2}c_t, \quad (5)$$

where c_t is the scattering coefficient of the target. It is assumed that $|c_t| \gg |c_i|$ and the target is fixed at $\boldsymbol{r}_t$. By applying (5) into (2) and let $\Delta t = T$, where $T >> 1$, then (2) becomes

$$S(T,t) = \frac{1}{C}\int_{f_c-\Delta f/2}^{f_c+\Delta f/2}\left|\frac{\rho_t}{(4\pi)^2\left|\boldsymbol{r}_t - \boldsymbol{r}_0\right|^2}\right|^2 df + \epsilon. \quad (6)$$

Note that due to the signal from the target, as expressed in (6), the PPC signal converges to an increased value than that of (4). Therefore, the detection can be easily done by comparing the PPC signals obtained from periodically measured channel responses.

III. Simulation Result

Here, we perform simulations as follows: 1000 clutters are uniformly distributed within the volume specified by $-4 \leq x \leq 4$, $-4 \leq y \leq 4$, and $-4 \leq z \leq 4$. The motion in the x, y, and z domain for each clutter is randomly generated using the Brownian power spectral density given by [4]

$$S_{x,y,z}(\omega) = \frac{S_F(\omega)}{(\alpha - m\omega^2)^2 + \beta^2\omega^2}, \quad (7)$$

where $S_F(\omega)$ is the power spectral density of the collision force and assumed to be normal white noise, α is the coefficient of the restoring force, m is the mass of the clutter, and β is the coefficient of friction. In the simulations, $S_F(\omega) = 2\times10^{-3}$, $\alpha = 1$, $m = 10$, and $\beta = 1$ are used. Then, (6) is calculated using the generated rich-clutter environment for every 0.01 s with $c_t = 0$ (no target case), 10, 20, and 30. The location of the target is $\boldsymbol{r}_t = 0\hat{r}$, where $\hat{r}$ is the unit vector along the radial vector.

Fig. 2 shows the simulation results of (2). The black solid line is used as the reference and the other lines are the phase conjugation signal obtained when the target is located. As can be seen, the target presence increases the level of the signal. Then, by dividing the obtained PPC signals to the reference, the energy ratio of the target to clutter is obtained and shown in Fig. 3. As can be seen, the target to clutter ratio increases as Δt increases, which can enhance the detection performance. However, the longer Δt, the slower the overall detection speed. The optimum value of Δt can vary depending on the target or the environment and is not discussed here, but left for future work.

IV. Conclusion

In this work, we proposed a detection scheme using the PPC technique and demonstrate this with simulations. To generate time-varying and rich-scattering channels, point clutters with random scattering coefficients and having Brownian motion are used. The simulation results show that the target presence causes the increased signal level difference. Moreover, by choosing the detection time longer, the difference can be increased. However, in terms of detection probability, this result is still questionable since increased detection time can be seen as sacrificing the speed of the detection process. In the future, various additional simulations, as well as studies based on rigorous approaches, are required to assess the gain provided from the proposed scheme.

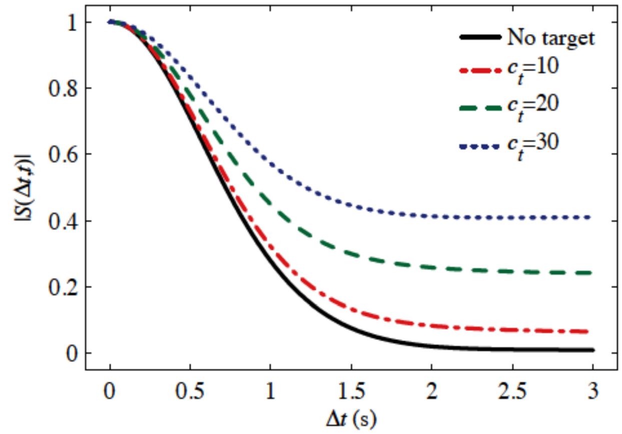

Fig. 2. Simulation results of PPC signal from the generated time-varying and clutter-rich environment with and without target.

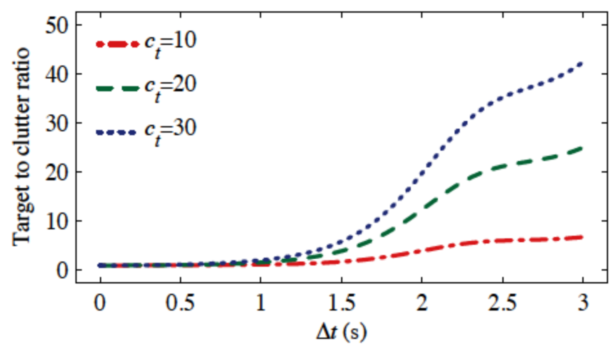

Fig. 3. Simulation results of target to clutter ratio from the generated time-varying and clutter-rich environment.

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