Coherent range and Doppler-walk compensation in PBR applications

(Invited Paper)

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***Abstract*—The focus of PBR research has shifted from FM to also include DVB-T and DAB over the last years, and are facing the challenges of higher bandwidth, i.e. improved range resolution. While the FM based PBR systems primarily had to deal with Doppler migration, the DVB-T based PBR systems are using CPIs which, combined with the higher bandwidth, leads to range and Doppler walk. The Doppler resolution is inversely proportional to the CPI, and longer CPI will therefore lead to finer Doppler resolution. And thus the higher bandwidth and longer CPI leads to increased propability of both range and Doppler walk. This paper describes a method to coherently compensate for both range and Doppler walk of targets already detected. The method coherently compensates both the translational movement and non-linear phase caused by range and Doppler walk.**

I. Introduction

In recent years, there has been a growth in PBR systems based on DVB-T and DAB. For PBR DVB-T, the bistatic range resolution is reported to be 40 - 50 meters [1], [2]. This type of systems have a bandwidth of 6-8 MHz [3] compared to FM based systems with 50-100 kHz, which leads to finer range resolution. The ability to increase the CPI can give more information on the target due to better Doppler resolution. The combination of finer range and Doppler resolution leads to a larger probability of range and Doppler walk [4] compared to FM based systems. Methods has been proposed in earlier work to mitigate range and Doppler walk, but they have been either based on non-coherent integration [4] or demanded a lot of processing power [5].

Once the target is detected, it is of interest to focus the target in range and Doppler as well as increase the SNR. The method proposed in [4] is based on non-coherent integration and does not compensate for Doppler walk, and in addition non-coherent integration is less efficient than coherent integration [6] considering SNR. While the method proposed in [5] compensates coherently for the motion of the target in the signal processing, the method proposed in this work process a window enclosing the target in the range-Doppler matrix. The processing load for each detected target is low due to the small amount of data compared to processing the entire signal for each target motion model. The proposed signal processing scheme is evaluated on simulated DVB-T datasets.

II. Simulations

A simple OFDM 64-QAM simulator is used to mimic the DVB-T signal. Pilot tones and TPS carriers is not applied to the signal, but all other DVB-T parameters for a set of Norwegian terrestrial broadcast transmitters have been used. The symbol data is drawn from a white gaussian process, and is according to [7] a good approximation to the signal. Both bistatic velocity and acceleration have been applied to the simulated target according to the model described in [5]. Figure 1a shows the range-Doppler surface of a simulated target resulting from a CPI of 4 seconds, bistatic range of $8km$, bistatic velocity of $95m/s$ and bistatic acceleration of $3m/s^2$. The target is streched over several range and Doppler bins and illustrates the effects of range and Doppler walk.

A. Range walk compensation

Range walk results from the signal processing not compensating for the bistatic velocity. The range-time image of a target in figure 2a show the target moving through several range bins during the integration interval, approxemately $400m$ during the CPI where the bistatic range resolution is $37.5m$.

The target velocity is assumend to be known, since it has been detected in both range and Doppler before the compensation process starts. The range walk compensation is performed in range-time domain, where a time dependent range compensation is applied based on the target velocity and range resolution. The Fourier transform of the range-time matrix is multiplied by a velocity and time dependent complex exponential, according to the DFT shift theorem [8].

$$\hat{x}(m,n) = \mathcal{F}^{-1}\{\mathcal{F}\{x(m,n)\} \times e^{i2\pi \frac{mv_b}{\Delta R}\frac{T_i}{M}\frac{n}{N}}\} \qquad (1)$$

Here, x is the range time matrix, $\hat{x}$ is the compensated range time matrix, $\mathcal{F}$ is the Fourier transform, v_b is the bistatic velocity, ΔR is the bistatic range resolution, T_i is the sampling period, M is the dimension size in time, N is the dimension size in range, $i = \sqrt{-1}$, $m = 0, 1, ..., M-1$ and $n = 0, 1, ..., N-1$. The time dependent range shift is done in the Fourier domain to avoid discrete phase jumps. If a discrete shift in the range domain were used, a discrete jump in the phase would occur at each range shift.

Figure 2b show the simulated target after range walk compensation. The linear range walk caused by the target velocity

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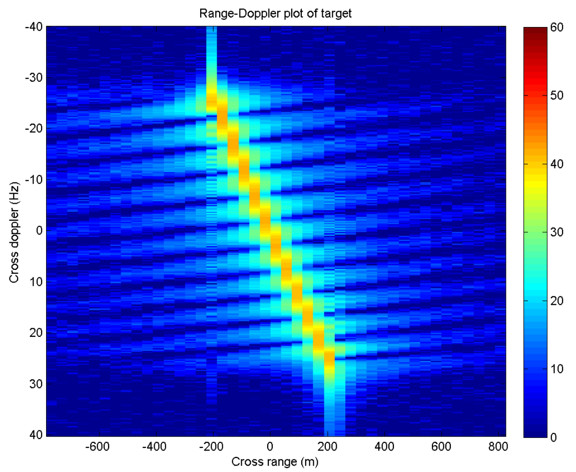
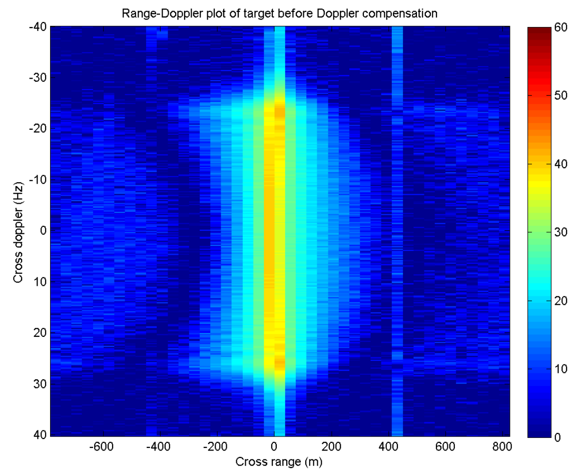
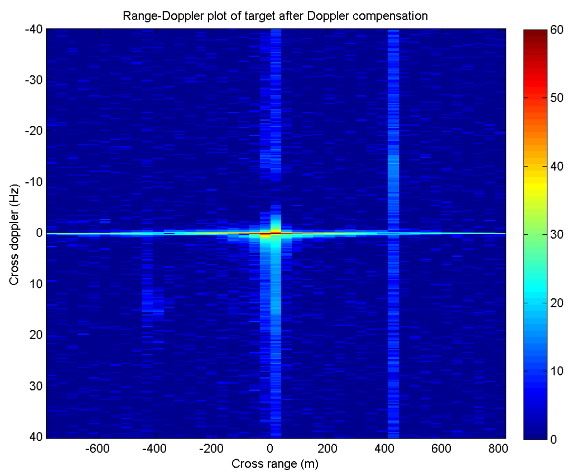


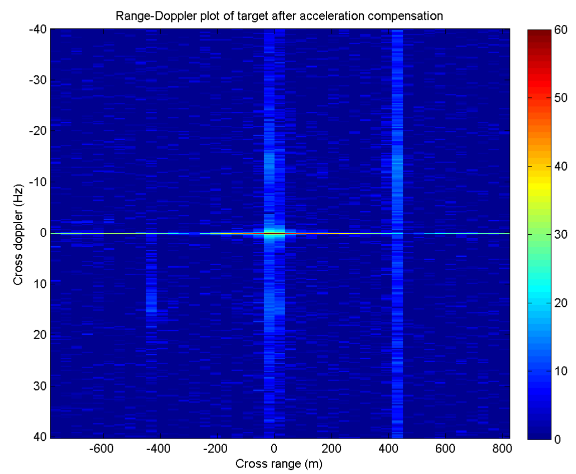
(a) Range-Doppler image of target showing range and Doppler walk



(b) Range-Doppler image of target after range walk compensation



(c) Range-Doppler image of target after range and Doppler walk compensation



(d) Range-Doppler image of target after acceleration induced range walk compensation

Fig. 1. Range-Doppler plots of a simulated target. Each plot show the improvement of range and Doppler walk compensation, where the velocity induced range walk is compensated from figure 1a to 1b. The velocity and acceleration induced Doppler walk is compensated in figure 1c, and the acceleration induced range and Doppler walk is compensated for in figure 1d.

is compensated, but a concave shape is visible caused by the target acceleration.

Doppler processing of the target after range walk compensation is shown in figure 1b. The target is compressed from a long ridge across range and Doppler before compensation, to a ridge across Doppler after compensation. The acceleration is visible as the concave light blue shape of the target, and large accelerations can produce range walk as is visible here.

B. Doppler walk compensation

The target velocity and acceleration leads to a polynomial phase, where the linear term is caused by the velocity and the quadratic term by the acceleration [9]. The presented method uses a curve fitting algorithm to generate a phase curve to compensate for the motion of the target. Steps have been incorporated into the algorithm to avoid discrete jumps in the phase caused by noise and other interference. Another possibility of estimating the phase of the target is by using a PGA [10], [11], which is a robust estimation algorithm for the phase gradient. The PGA estimates the phase gradient in one range cell, and using this gradient for phase compensation will compress all scatterers into one range-Doppler cell. Separating closely spaced scatterers in range and Doppler is therefore not possible with this method.

The phase is compensated for in the range-time domain, where a complex exponential with the conjugate of the estimated phase curve is multiplied in the time domain on each range bin. This compensates for the velocity and acceleration contribution for the target. After compensating for the target velocity and acceleration with the phase curve, the target is focused in Doppler. This can be seen in figure 1b to 1c, where

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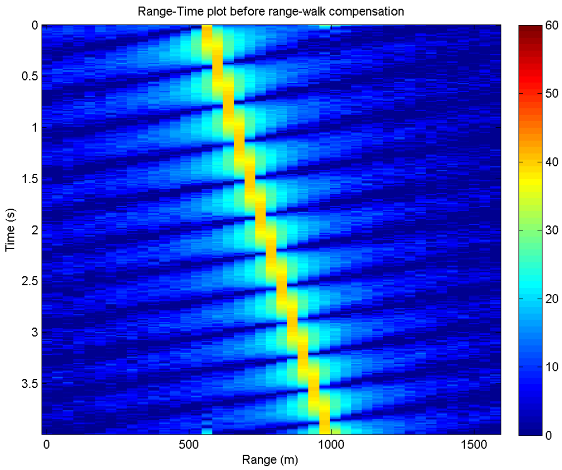
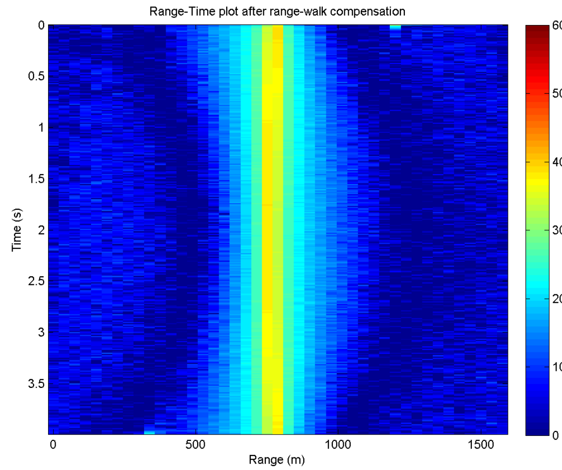
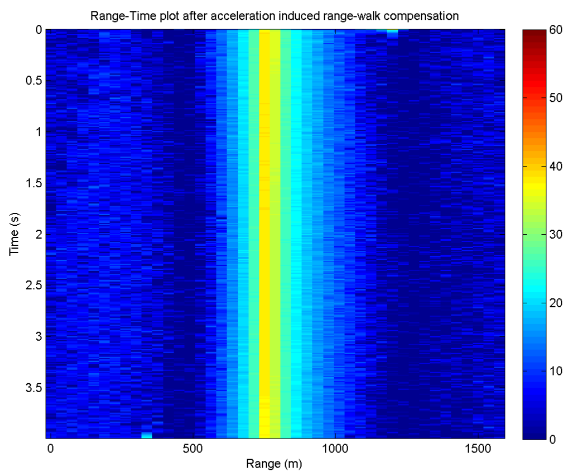


(a) Range-time plot of target



(b) Range-time plot of target after range walk compensation



(c) Range Doppler image of target after range and Doppler walk compensation

Fig. 2. Range-time plots of a simulated target. Each plot show the improvement of range walk compensation, where the velocity induced range walk is compensated for in figure 2a to 2b. The acceleration induced range walk is compensated for from figure 2b to 2c.

the target is focused from a broad ridge into a narrow peak.

The target has an acceleration of $3m/s^2$, and will therefore have a velocity change within the CPI. This velocity change will cause a range walk which can be seen both in figure 2b as a concave form of the compensated target, and in figure 1c as a unfocused target in range and Doppler.

C. Range and Doppler walk compensation

The phase estimation give an estimate of both velocity and acceleration of the target. The velocity is the linear term of the phase evolution, and the acceleration is the quadratic term. The range walk caused by a velocity is compensated for in the first step of the algorithm. By using the estimate of acceleration, the acceleration induced range walk can be compensated for in the range-time domain with a quadratic range walk compensation function.

After compensating for range-walk induced by acceleration, the phase over the target is again estimated, and the phase is then compesated for in the range-time domain with a complex exponential with the conjugate phase. Figure 1d shows the compensated target in the range-time domain. The target stay within one range bin during the CPI, and as described in figure 1d is focused in both range and Doppler.

Figures 3a and 3b show a range and Doppler cut of the target before (figure 1a) and after (figure 1d) range and Doppler walk compensation. We can see from these figures that the SNR increase with approxemately $20dB$ after range and Doppler walk compensation.

III. Conclusions

This paper show that for a simulated target in a DVB-T based PBR system, it is possible to increase the CPI above the thresholds which induce range and Doppler walk for a given target. The method described is coherent, and therefore

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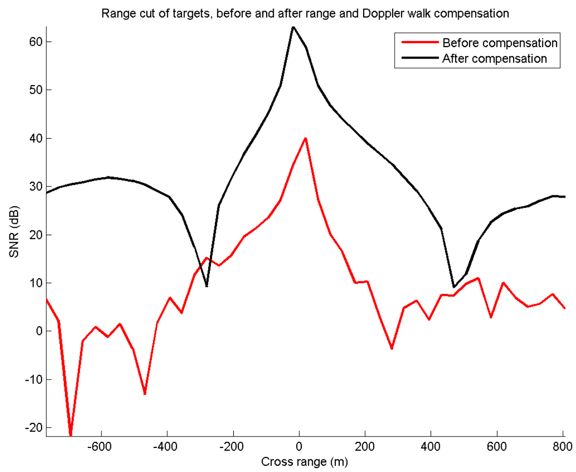
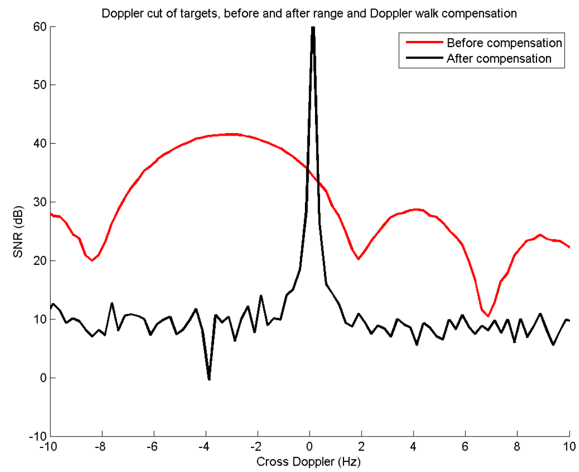


(a) Range cut of target before and after range and Doppler walk compensation



(b) Doppler cut of target before and after range and Doppler walk compensation

Fig. 3. Figure 3a show a range cut, and figure 3b show a Doppler cut of the target before and after range and Doppler walk compensation. The range and Doppler migration is shown as the wide compared to the narrow response before and after the compensation. The range Doppler image before range and Doppler walk compensation is shown in figure 1a, and after the compensation in figure 1d.

the integration gain is high compared to other non-coherent methods proposed [4]. The processing required for each target is low compared to other coherent methods for compensating range and Doppler walk [5].

The simulations show that a range and Doppler walk compensated target is focused in range and Doppler, which is required for using multiband techniques to increase the range resolution. The SNR is increased with 20 dB by using this method. The combination of a focused target, high SNR and a fine Doppler resolution can give important information on the target.

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