APPLICATION OF MOVING TARGET DETECTION BY FOCUSING TECHNIQUE IN CIVIL TRAFFIC MONITORING

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1. INTRODUCTION

Civil traffic monitoring has attracted considerable interest recently as the number of transport increases in quantity and complexity. Currently used monitoring systems are mainly based on imaging sensors, for example traffic cameras. Such systems may provide coverage of narrow areas of terrain and can only operate in certain conditions. Civil traffic monitoring using airborne and spaceborne Synthetic Aperture Radar (SAR) is seen as an alternative to meet the requirements of wide coverage and severe conditions. Some strategies using SAR for traffic monitoring have been proposed recently, for example in [1].

Essential tasks of civil traffic monitoring include detection of multiple vehicles, speed estimation and imaging the vehicles of interest. Basically, such tasks require Ground Moving Target Indication (GMTI) techniques, estimation methods as well as imaging algorithms. A comprehensive solution for civil traffic monitoring is still required. This mean, instead of using a separate approach for each task, a comprehensive solution is expected to perform all the civil traffic monitoring tasks simultaneously.

Recently, a new GMTI technique named as Detection of Moving Target by Focusing (DMTF) has been proposed [2]. Although this technique aims at Ultra-wideband SAR systems it is also completely available for narrowband SAR systems. The ability to detect a moving target increases significantly when the moving target is first focused with an approximately true Normalized Relative Speed (NRS). The measured improvement of the Signal-to-Clutter Noise Ratio (SCNR) is up to approximately 20 dB using single channel data. The experimental results also show that initial estimations of movement parameters are possible. Since DMTF is developed on an imaging algorithm, the moving target can be imaged directly. As shown in [2], the basis of DMTF can be imaging algorithms both in time- and frequency-domain. For these reason, DMTF can be seen as a promising technique for civil traffic monitoring.

The goal of this paper is to study the possibility of applying DMTF to civil traffic monitoring. Since in a civilian scenario the traffic travels along roads with know angles [1], this information may be used to solve the so-called invisible moving angle which would otherwise be a shortcoming of DMTF [2]. Data used in the experiments is simulated according to the LORA parameters [4] configured for GMTI purposes. Ultra-wideband Chirp Scaling (UCS) [5], which is a Chirp Scaling algorithm adapted for UWB and GMTI SAR data processing, is selected as the basis for the focusing approach of DMTF.

2. DETECTION OF MOVING TARGET BY FOCUSING TECHNIQUE

DMTF is based on the concept of Normalized Relative Speed (NRS) [2]. According to this concept, a moving target, which is normally displaced and defocused as an elliptic or hyperbolic curve in a SAR image, can be focused to its original shape in the SAR image. For detection, different hypotheses γ_p (so-called NRS under test) on γ_t have to be tested on an observed area of interest until the detection is reached. The range of γ_p is found from the maximum speed of the target v_{tg}, which is expected to detect, and the platform speed v_{pl}

$$\gamma_p \in \left[1 - \max\left\{\frac{v_{tg}}{v_{pl}}\right\}, 1 + \max\left\{\frac{v_{tg}}{v_{pl}}\right\}\right]. \tag{1}$$

An optimum relative speed discretisation between hypotheses γ_p for detection is proposed in [6] as

$$\Delta\gamma \approx \frac{Q^2 c r_0}{2\pi f_c \gamma_t v_{pl}^2 t_i^2}. \tag{2}$$

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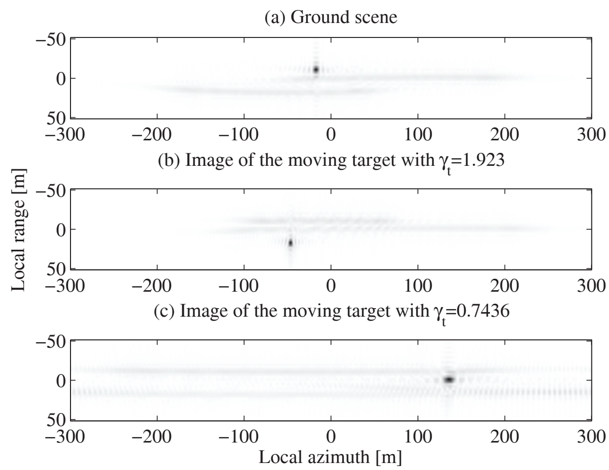

Fig. 1. The SAR image of the ground scene as well as the images of the vehicles processed. (a) The ground scene, (b) the target moving with $\gamma_t = 0.7436$, (c) the target moving with $\gamma_t = 1.1923$.

where f_c is the center frequency and t_i is the integration time. The detection constant Q is given by a threshold h_{lim} which should be set according to the requirement of the detection failure rate. For detection, the threshold is normally set to $h_{lim} = -3$ dB, i.e. giving a maximum loss of 3 dB from the peak Impulse Response (IR).

DMTF allows us detecting multiple moving targets as a result of testing different hypotheses γ_p. It also allows estimating approximately the true NRS γ_t of the detected moving targets. To reach a more accurate γ_t, testing hypotheses should be repeated with smaller step size $\Delta\gamma$ and in a smaller interval of the new hypotheses around γ_p found in the detection stage.

3. APPLICATION OF DMTF IN CIVIL TRAFFIC MONITORING

Detection of multiple moving vehicles, estimating their speed and imaging them are seen as basic tasks in civil traffic monitoring. It is more likely that roads or streets, which need to be monitored, are known. In other words, the moving directions of the vehicles in short integration time are normally known [1]. Applying DMTF to civil traffic monitoring has several advantages as follows. Firstly, the ability of DMTF to detect multiple moving targets simultaneously is extremely important for high traffic density monitoring nowadays. Secondly, with a known moving direction φ of a vehicle with respect to the platform velocity vector $\vec{v}_{pl}$, the speed of the vehicle v_{tg} can be estimated directly from

$$v_{tg} = v_{pl}\left(\cos\varphi \pm \sqrt{\gamma_t^2 - \sin^2\varphi}\right). \tag{3}$$

Thirdly, the detected vehicles of interest can be imaged with the estimated γ_t. Finally, the inherent shortcoming of DMTF in single-channel SAR, which is connected to the so-called invisible moving angle φ_i [3], can be handled easily in the civil traffic monitoring application

$$\varphi_i = \cos^{-1}\left(\frac{v_{tg}}{2v_{pl}}\right), \tag{4}$$

Based on a possible speed range of the vehicles, a range of invisible moving angles can be determined by (4). The optimum relative speed discretisation $\Delta\gamma$ is proposed on the detection's point of view, i.e. the acceptable detection failure decides $\Delta\gamma$. In the estimation stage, this discretisation should be reduced to get a better estimation of NRS. From the speed estimation's point of view and in the civil traffic monitoring application, the discretisation for estimation should be set to meet demand for estimation error. If we define ϵ as the acceptable estimation error, the discretisation for estimation $\Delta\gamma_e$ is derived from (3) as

$$\Delta\gamma_e = \pm\gamma_t - \sqrt{\left[\pm(1-\epsilon)\sqrt{\gamma_t^2 - \sin^2\varphi} - \epsilon\cos\varphi\right]^2 + \sin^2\varphi} \tag{5}$$

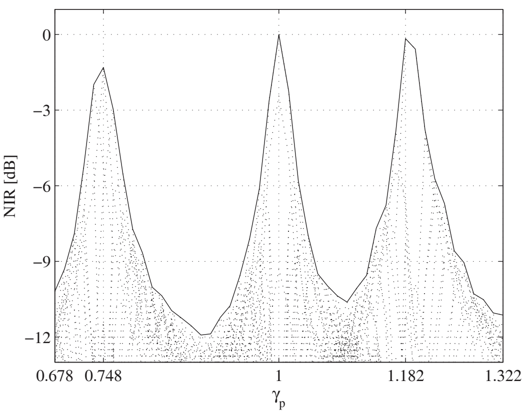

Fig. 2. The 2D-map of NIR measured on the area of interest being tested by 47 hypotheses γ_p. The solid black plots denote the envelop of NIR. The peaks indicate one stationary vehicle ($\gamma_p = 1$) and the moving vehicles with $\gamma_t \approx 0.748$ and $\gamma_t \approx 1.182$.

4. SIMULATION AND EVALUATION

In this section, we present some simulation results to illustrate the application of DMTF in civil traffic monitoring. The reference SAR system for the simulation is LORA [4] operating in the frequency range of $307.2 - 332.8$ MHz. The flight track is assumed to be linear and the speed of the platform is a constant $v_{pl} = 130$ m/s. The platform is assumed to fly parallel to the road, i.e. either $\varphi = 0^{\text{o}}$ or $\varphi = 180^{\text{o}}$ depending on the moving direction of the vehicles. With this assumption, there is no Doppler shift. For illustration purposes, a simple ground scene including only two vehicles moving on a straight road and one parking on the kerb of the road is simulated. The clutter and noise are Additive White Gaussian Noise (AWGN) and the Signal-to-Clutter-Noise Ratio (SCNR) is -10 dB. All vehicles are simulated as point-like scatters. Their Radar Cross Section (RCS) are normalized to $\sigma = 1$. Among two moving vehicles, one moves with the constant speed of 120 km/h (33.3 m/s) to the flying direction and the other 90 km/h (25 m/s) to opposite direction in the considered integration time. The first vehicle results in a true NRS $\gamma_t = 0.7436$ and the latter $\gamma_t = 1.1923$. In the civil traffic monitoring application, the vehicle speed can be limited in a range $[0, 150]$ km/h or $[0, 41.7]$ m/s. The corresponding range of the invisible moving angle of $[\pm 70^{\text{o}}, \pm 90^{\text{o}}]$ is estimated by (4). The range of the invisible moving angle is seen to be narrow and does not cause any difficulty for the platform. The ground scene is processed by the UCS with a scaling factor of $\gamma_u = 2.4$ and imaged in Fig. 1.

If the basis for the focusing approach of DMTF is also integrated in UCS, testing hypotheses γ_p is implemented by defining the term β in UCS as

$$\beta = \sqrt{1 - \frac{1}{\gamma_p^2}\left(\frac{\mathrm{c} f_x}{2 f_c v_{pl} \gamma_u}\right)^2}. \tag{6}$$

where f_x denotes the azimuth frequency. A range of tested hypotheses $\gamma_p \in [0.678, 1.322]$ are retrieved from (1). Equation (2) results in an optimum relative speed discretisation between hypotheses $\Delta\gamma = 1.4 \cdot 10^{-2}$. The number of hypotheses, which needs to be tested, is therefore $N_h = 47$. The area of interest is clearly defined by the stretch of road which needs to be monitored. To meet the requirement of the image pixel spacing for detection [2], the area of interest processed by UCS should be downsampled by a factor of about fifty (50) in azimuth and about two (2) in range to obtain $\Delta x \times \Delta r \approx 5\text{m} \times 5\text{m}$ [2].

Fig. 2 shows the 2D-map of all Normalized SAR Impulse Response (NIR) belonging the defined area of interest as a function of γ_p. The solid black plots denote the envelop of NIR in the 2D-map. The peaks are found at the hypotheses $\gamma_p = 0.748$, 1 and 1.182. This corresponds to the stationary vehicle and two moving vehicles in the simulated ground scene. Equation (3) results in a set of roots as

γ_p	φ	v_{pl}
0.748	0^{o}	818 km/h and 118 km/h
	180^{o}	-818 km/h and -118 km/h
1.182	0^{o}	1021 km/h and -85 km/h
	180^{o}	-1021 km/h and 85 km/h

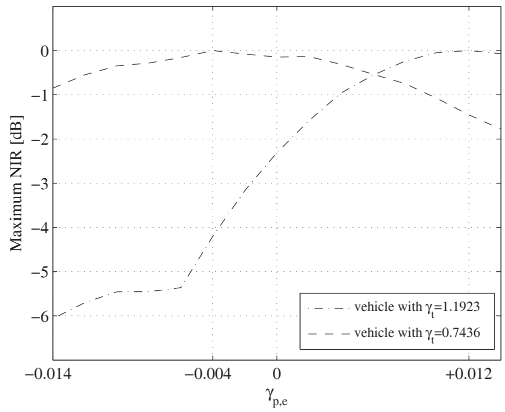

Fig. 3. The maximum NIR measured on the area of detection being tested in the ranges of 21 hypotheses $\gamma_{p,e}$. The new estimated NRS are $\gamma_{p,e} = 0.748 - 2 \times 2 \cdot 10^{-3}$ and $1.182 + 6 \times 2 \cdot 10^{-3}$. The accuracy of these estimation is up to 99%.

It is obvious that there are only two true roots $v_{pl} = 118$ km/h and $v_{pl} = 85$ km/h corresponding to $\varphi = 0^o$ and $\varphi = 180^o$, respectively. Errors in these estimations are 1.6% and 3.4%. Such small errors indicate that the optimum relative speed discretisation is not only reasonable for detection but also for estimation. No further estimation is needed for normal civil traffic monitoring. With the estimated speeds in the detection stage, we can focus the vehicles to their original shapes (point-like scatters). Fig. 1.b and 1.c show the image of these vehicles.

In some special cases, more accurate estimations may be required. In such cases, we can again test new hypotheses in new smaller ranges of $\gamma_{p,e} \in [\gamma_p - \Delta\gamma, \gamma_p + \Delta\gamma]$ with a smaller step size on the areas of detection [2]. Assuming that, we need to estimate the speeds of the vehicles with the expected error $\epsilon \leq 1\%$. Due to the sensitivity of the vehicle with $v_{pl} = 85$ km/h and $\varphi = 180^o$ to the estimation error, it is used to calculate in (5) which results in a discretisation for estimation $\Delta\gamma_e = 2 \cdot 10^{-3}$. The new ranges of hypotheses are $\gamma_{p,e} \in [1.168, 1.196]$ and $[0.734, 0.762]$. Fig. 3 shows the maximum NIR in the areas of detection. The new estimated NRS are $\gamma_{p,e} = 1.194$ and $\gamma_{p,e} = 0.744$. The new estimated speeds of the vehicles are $v_{pl} = 119.8$ km/h and $v_{pl} = 90.8$ km/h. The estimation errors are reduced to 0.16% and 0.88%.

5. CONCLUSION

In this paper, we presents an application of DMTF in civil traffic monitoring. The simulation results on a single-channel airborne SAR system show that DMTF allows detecting multiple vehicles, estimating their speed and imaging the detected vehicles. In this application, the knowledge of civilian scenarios facilitates solving the invisible moving angle - a shortcoming of DMTF.

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