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# REALISTIC SHIP MODEL FOR EXTENDED TARGET TRACKING ALGORITHMS

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**ABSTRACT**

Recent developments in high resolution sensors have encouraged the use of Extended Target Tracking (ETT) algorithms specifically designed to deal with targets that generate more than one detection per frame. At the same time, the availability of more powerful computational resources enable the use of soft computing techniques that yield a target probability, instead of a hard decision. This paper proposes a realistic target model feasible for an Extended Target - Track before Detect framework. Physical phenomena related to the acquisition of high resolution X-band marine radar data are considered. Real radar data is used to assess the superior performance of the featured model with respect to previous approaches. Results show that the realistic model provides better estimations of the target velocity and size.

***Index Terms*—** Radar tracking, Radar remote sensing, Feature extraction, Extended Target Tracking, Track before Detect, X-band radar

## 1. INTRODUCTION

Among the technologies used for target detection and tracking, radar is probably the most widespread. Advances in pulse compression techniques [1] permit the generation of high resolution radar data, where targets generally occupy more than one resolution cell. As a consequence, the common hypothesis used in target tracking, *i.e.* the target generates at most one detection per radar frame, is no longer valid. Specific techniques, known as Extended Target Tracking (ETT) algorithms, have been developed to deal with this problem. Most of them rely on an elliptic representation of the target, *e.g.* [2, 3]. A review of Sequential Monte Carlo methods for ETT can be found in [4].

At the same time, the availability of more powerful computational resources make feasible to perform the target detection and tracking stages in one single step. Former approaches used a hard detector as first stage of a detection and tracking algorithm. This approach, although computationally efficient, results in a loss of information and may result in the miss-detection of low observable targets. The output of the detection stage was then used to feed a tracker. Track before Detect (TbD) techniques are computationally more demanding, but they make use of all the information contained in each radar frame. An ETT-TbD approach was introduced in [5], that is capable of simultaneously detecting and tracking targets, providing a probability of target based on a probabilistic model rather than a hard decision between the target presence or absence.

However, the probabilistic model introduced in [5] did not take into account several physical phenomena involved in the scenario and, therefore, the target size estimation was biased. This paper explores some of these phenomena and proposes an enhanced realistic model. The new model is compared with the previous approach using real radar data obtained with the Marine Radar Node (MRN) of the Radar Sensor Network (RSN), an X-band configurable Linear Frequency Modulated Continuous Wave (LFMCW) [1] radar, installed in the Gulf of La Spezia, Italy.

The remainder of the paper is organized as follows: Section 2 describes the phenomena involved in the radar acquisition and introduces the model. Section 3 presents a deterministic example of the model and Section 4 presents results when the featured model is applied to real radar data and provides a comparison with the former model. Finally, Section 5 draws the conclusion of the paper.

## 2. DESCRIPTION OF THE REALISTIC MODEL

As opposed to [5], where both the backscattered power of target and the clutter were considered exponentially distributed (*Exp.* model) and the target/clutter decision for each cell in the radar plot follows a purely geometrical model that assumed an elliptical target (*Geom.* model), this new realistic model takes into consideration some of the physical phenomena involved in the acquisition of data with a real world, hence non-ideal, LFMCW marine radar.

The first two phenomena apply only under the well-known assumption of Geometrical Optics (GO), *i.e.* when the transmitted wavelength is much smaller than the maximum size of the objects involved in the propagation mechanism. The shadowing phenomenon occurs when the illuminated region of a large target creates a shadow region in which scatterers are not reached by radiation, and hence do not contribute to the backscattered signal. The multipath phenomenon, however, can only appear when the sea behaves as a *quasi-Perfect Electric Conductor* (PEC). This condition is met for low-grazing angles, horizontal polarization, calm sea, and when the divergence factor due to Earth's curvature is negligible [6]. As a consequence, multiple-bounce paths may produce delayed replicas at the receiver interpreted as fictitious detections at further ranges [7].

A third effect is always present in surveillance systems with a rotary antenna and it is related to the antenna's radiation pattern, which acts as a spatial filter on the backscattered signal. The signal at the receiver is actually modelled as a convolution between the backscattered one and the radiation pattern, causing an energy spread along the azimuth dimension.

The fourth phenomenon involved in the data acquisition is related to the processing of the waveform. In order to obtain a High

Resolution Range Profile (HRRP) from a LFMCW radar, a Fast Fourier Transform (FFT) is executed. It is commonplace to apply a windowing function to reduce the sidelobes after the FFT. The reduction of the sidelobe level comes at the cost of an enlarged main lobe. According to this, any point scatterer will appear in the radar data with an enlarged extent, along the range dimension. Thus, the size of a target in the radar plot is larger than its actual size. This effect is the result of a convolution in the range domain, due to the product with the windowing function in the frequency domain.

The effect of these two phenomena can be considered in one single step, assuming a two-dimensional Point Spread Function (PSF), which accounts for the spread in range due to the windowing and the spread in azimuth due to the radiating system's lobe width.

The last phenomenon is related to the antennas' radiation pattern. As a matter of fact, the presence of land structures or ships outside the Field of View (FOV) can give rise to apparent targets inside the FOV due to the high sidelobes which characterize the antenna's radiation pattern. The level of these *ghost targets* is much smaller than the real ones, but in order for the algorithm to consider them as clutter, a proper probability distribution for the clutter must be defined, instead of the exponential distribution. Regarding the target, different structures, such as cavities or metallic surfaces perpendicular to the propagation, can generate very high reflections in a stochastic manner. Hence, a probability distribution for the target's backscattered power should also be defined. Since these effects in the clutter and the target are caused by the same phenomena, one single probability distribution will be used, with different parameters for the clutter and target. The proposed distribution is a continuous density with the shape of a truncated hyperbole in the linear scale or, which is equivalent, a uniform distribution in the dB scale [8].

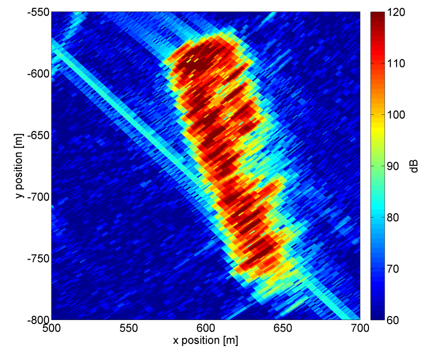
## 3. AN EXAMPLE

Although the realistic model is probabilistic by nature, some of the electromagnetic effects have been considered in a deterministic way to generate synthetic data and verify its resemblance to the real radar data. A real radar acquisition of a large cruise ship is shown in Fig. 1(a). As well as the target, an undesired interference (straight line across the plot) can be noticed. The synthetic data has been generated using the target's location, orientation and dimensions as retrieved from the AIS data plus some information regarding its height at different parts of its plan. A plot of the synthetic data is shown in Fig. 1(b).

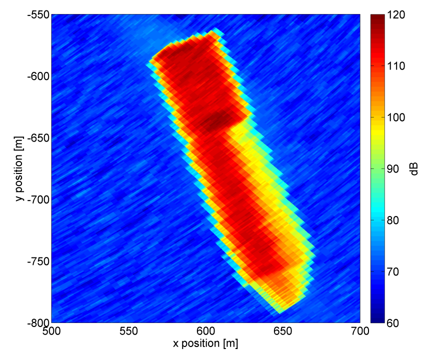
The data shown in Fig. 1(b) takes into account the multipath and shadowing effects, plus the 2D convolution with system's PSF. Nevertheless, the stochastic behaviour of the target's radar return is not considered and, therefore, the synthetic data does not show the variability that can be seen in the real data.

The resemblance between the real and the synthetic data is clear, what leads to the consideration of the aforementioned phenomena in the probabilistic model.

For most small targets, however, it has been seen that the effect of the multipath is negligible and, also, that the shadowing effect, which is naturally spatially dependent, can be considered as an increased variability of the target's radar return. Hence, the probabilistic implementation of the realistic model will overlook the multipath effect and will consider that the cell measurements are conditionally independent, taking the shadowing effect into account as an increased support of the target's backscattering distribution, *i.e.* the limits of the hyperbolic distributions that rule the backscattering will show a large span.




(a) Real target




(b) Synthetic target

**Fig. 1**: The real target and its synthetic representation based on the proposed model

| Parameter | Value |
|---|---|
| Central Frequency | 9.6 GHz |
| Bandwidth | 150 MHz |
| Pulse Repetition Frequency | 0.699 kHz |
| Baseband Sampling Frequency | 10 MHz |
| Antenna Rotation Speed | 20 RPM |
| Period between frames ($T$) | 3 s |
| Transmitted Power | 24 dBm |
| Range Resolution | 1m |
| Angular Resolution | 0.172° |
| Polarization | Horizontal |

**Table 1**: Configuration parameters of the radar system during the target acquisition

## 4. REAL DATA ANALYSIS

The featured model has been studied with real data and compared against the previous *Geom-Exp* model [5]. Details on the implementation of the realistic model can be found in [8].

Validation of the model was executed on real radar data from a target of opportunity: a tug boat with a length of a 28.7m and a beam of 10.4m, as shown in Fig. 2. The radar acquisition was performed with the parameters shown in Table 1. For both models, the target motion and existence parameters were the same (see Table 2) and both particle filters used the same number of particles $N_p = 1000$.


**Fig. 2**: Tug boat used for validation [9]

| Parameter | Value |
|---|---|
| Probability of target death | $10^{-6}$ |
| Probability of target birth | $10^{-6}$ |
| Acceleration (noise) of the $x$ coordinate | $10^{-2}\mathrm{m/s}^2$ |
| Acceleration (noise) of the $y$ coordinate | $10^{-2}\mathrm{m/s}^2$ |
| Typical deviation of the length | 2m |
| Typical deviation of the width | 2m |

**Table 2**: Parameters of the target existence and motion model

| Parameter | Value |
|---|---|
| $\mu_0$ | $10^6$ (60dB) |
| $\mu_1$ | $10^{13}$ (130dB) |

**Table 3**: Parameters of the exponential target model

| Parameter | Value |
|---|---|
| $q_1$ | $10^1$ (10dB) |
| $q_2$ | $10^{10}$ (100dB) |
| $s_1$ | $10^8$ (80dB) |
| $s_2$ | $10^{14}$ (140dB) |

**Table 4**: Parameters of the hyperbolic target model

Specific parameters of each target model are shown in Table 3 for the *Geom-Exp* model and in Table 4 for the realistic model. Parameters $\mu_0$ and $\mu_1$ are the expected values of the exponentially distributed clutter and target in the first model, respectively. For the second model $q_1$ and $q_2$ are the minimum and maximum limits of the hyperbolic distribution of the clutter, while $s_1$ and $s_2$ are the limits of the hyperbolic distribution of the target, respectively.

Results on real data using both the *Geom-Exp* and the realistic models are depicted in Fig. 3, where Figs. 3(a) and 3(b) show the $x$ and $y$ position, Figs. 3(c) and 3(d) show the $x$ and $y$ velocity and Figs. 3(e) and 3(f) show the length and width, respectively.

The two models yield a similar result in the target position estimation, shown in Figs. 3(a) and 3(b). However, a significant improvement in the velocity and size estimation has been obtained by means of the realistic model with respect to the *Geom-Exp* one.

It is clear that the *Geom-Exp* model yields a much more noisy estimate of the velocity than the realistic model. This is a consequence of a particle degeneration effect that makes the output of the particle filter present abrupt oscillations rather than a smooth output. The featured model provides a smoother velocity estimation because the hyperbolic distribution generates more even values of the likelihood. On the contrary, the exponential distribution yields very uneven values that span along a very large range.

The previous *Geom-Exp* model produces a significant overestimation of the target's size, since the radar plot of the target is larger than the actual target. The realistic model considers the mismatch between the actual target's size and the size of the radar plot with the PSF and provides a better estimation of the target's extent. In the last timestamps of the data, the target's velocity is near zero, which results in a target course uncertainty what makes it more difficult for both models to provide a proper estimation of the target's size.

## 5. CONCLUSION

This paper presents a realistic extended target model for Track before Detect. It uses a truncated hyperbolic distribution for the distribution of the radar return from both the target and the clutter, and takes into account the Point Spread Function of the radar system in order to achieve a more precise target tracking along with a much more accurate target size estimation.

Results show that the target model should consider the physical phenomena involved in the data acquisition to achieve good tracking and feature extraction performances.

## 6. REFERENCES

[1] D. R. Wehner, *High resolution radar*, Artech House, Inc. Norwood, MA., 1987.

[2] J.W. Koch, “Bayesian approach to extended object and cluster tracking using random matrices,” *IEEE Trans. Aerosp. Electron. Syst.*, vol. 44, no. 3, pp. 1042–1059, July 2008.

[3] G. Vivone, P. Braca, and B. Errasti-Alcala, “Extended target tracking applied to X-band marine radar data,” in *Proc. of the MTS/IEEE Oceans Conference, Genova*, May 2015.

[4] L. Mihaylova, A. Carmi, S. François, A. Gning, S. Pang, and S. Godsill, “Overview of bayesian sequential monte carlo methods for group and extended object tracking,” *Digital Signal Processing*, vol. 25, pp. 1–16, 2014.

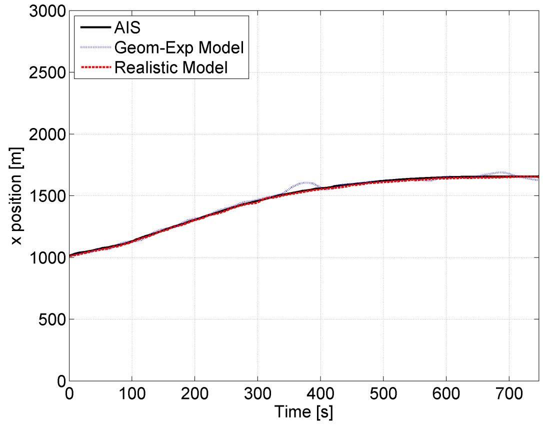
[5] B. Errasti-Alcala and P. Braca, “Track before detect algorithm for tracking extended targets applied to real-world data of X-band marine radar,” in *Proc. of the* $17^{th}$ *Intern. Conf. on Inform. Fusion (FUSION)*, 2014.

[6] J. N. Briggs, *Target Detection by Marine Radar*, IET Library. London, UK, 2004.

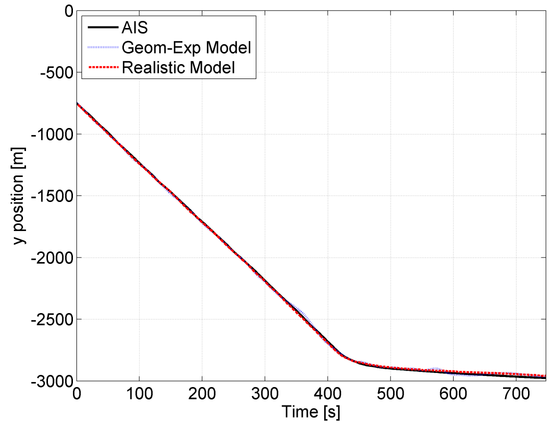
[7] H. A. Corriher Jr., “Multipath Phenomena and Effects,” in *Principles of Modern Radar*, J. L. Eaves and E. K. Reedy, Eds., pp. 72 – 103. Springer, New York, 1987.

[8] B. Errasti-Alcala, W. Fuscaldo, P. Braca, and G. Vivone, “Realistic extended target model for track before detect in maritime surveillance,” in *Proc. of the MTS/IEEE Oceans Conference, Genova*, May 2015.

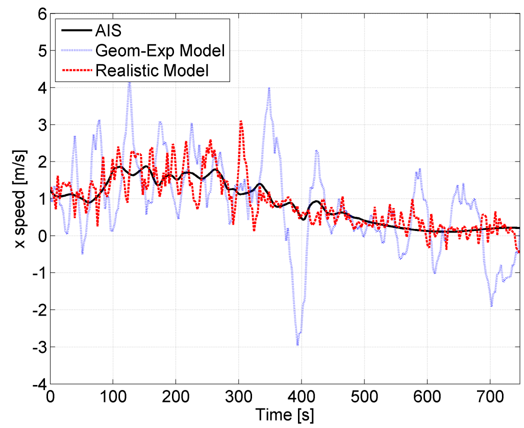
[9] M. Howlett, *Portovenere - MarineTraffic*, [Online]. Available: www.marinetraffic.com/en/ais/details/ships/shipid:274930.



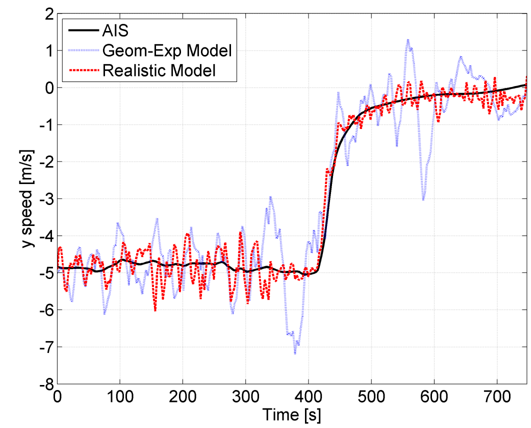

(a) Target's $x$ position



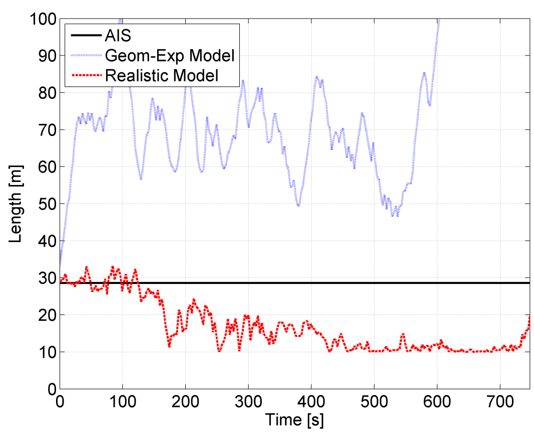

(b) Target's $y$ position



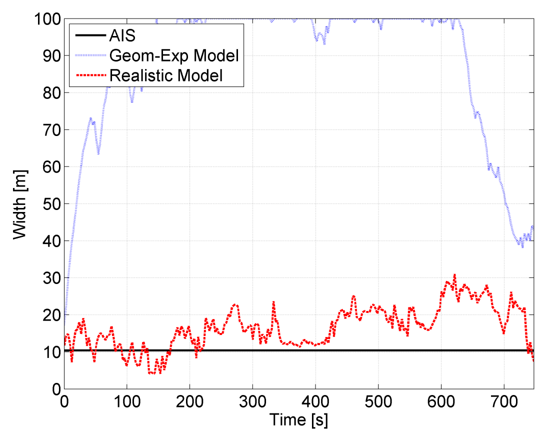

(c) Target's $x$ velocity




(d) Target's $y$ velocity




(e) Target's length




(f) Target's width

**Fig. 3**: Results of the compared approaches along with the AIS retrieved information

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*Abstract*

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