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Tracking of maneuvering non-ellipsoidal extended target with varying number of sub-objects

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A target that generates multiple measurements at each time step is called the extended target and an ellipse can be used to approximate its extension. When the spatial distributions of measurements can reflect its true shape, in this situation the extended target is called a non-ellipsoidal extended target and its complicated extended state cannot be accurately approximated by single ellipse. In view of this, the non-ellipsoidal extended target tracking (NETT) filter was proposed, which uses multiple ellipses (called sub-objects) to approximate the extended state. However, the existing NETT filters are limited to the framework that the number of sub-objects remains still, which does not match the actual tracking situations. When the attitude of the target changes, the view from the sensor on the target may change, then the shape of the non-ellipsoidal extended target varies as well as the reasonable number of sub-objects needed for approximation. To solve this problem, we propose a varying number of sub-objects for non-ellipsoidal extended target tracking gamma Gaussian inverse Wishart (VN-NETT-GGIW) filter. The proposed filter estimates the kinematic, extension and measurement-rate states of each sub-object as well as the number of sub-objects. The simulation results show that the proposed filter can be used for the target changing attitude situation and is more close to the practice application.

1. Introduction

The essence of target tracking is estimating the real-time states of targets from a sequence of measurements obtained from clutter, false alarms and targets [1]. According to the number of measurements generated by a target at each time step, the target tracking can be defined as the point-target tracking and extended-target tracking, separately. Seen from Fig. 1(a), the point-target tracking problem [2–13] assumes that each target can generate at most one measurement at each time step, which is true when the distance between the sensor and the target is large. Nevertheless, with the development of modern sensors or the aforementioned distance is relative small, there is a situation that a target may generate more than one measurement, see Fig. 1(b), and the extended-target tracking problem [14–22] arises. The generation of more than one measurement is due to the occupation of multiple resolution cells of each target, and more accurately information of target can be abstracted than that in point-target tracking case. The applications of the extended target tracking include person tracking using range sensor, visual tracking system, vehicle tracking using automotive radar, etc.

In addition to estimating the kinematic states of extended targets, it is also necessary to estimate the extended states of targets. The random matrix [23–28] and random-hypersurface [29–32] are the two main approaches of modeling the

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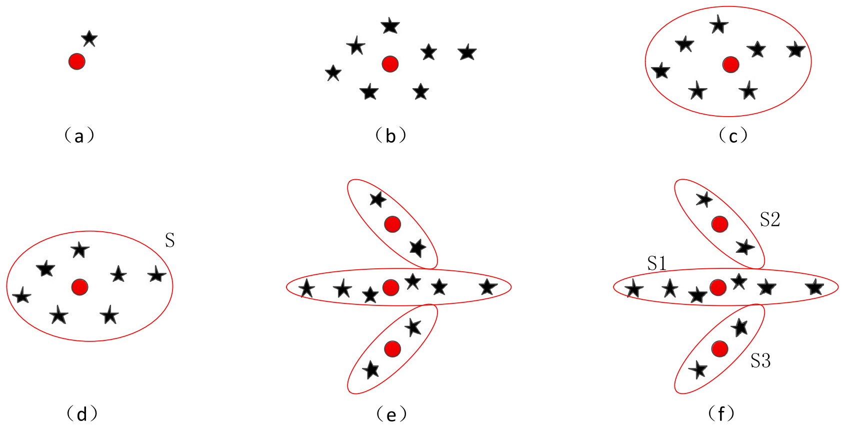

Fig. 1. Different measurement models and states of targets. A black star represents a measurement, the red point, red ellipse and given number S represent the estimations of the kinematic, extension states and measurement rate, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

extended states. Especially, the random matrix approach, initialed by Koch [23], attracts great attentions recently. Assuming no specific structure information of targets, the random matrix approach models the extended state as an ellipse using a symmetric positive defines (SPD) matrix (namely the random matrix), see Fig. 1(c). In order to meet the conjugate rule in iterative estimation, [23] intuitively replaces the covariance of observation noise with the SPD matrix. The suggested filter, named the Gaussian inverse Wishart (GIW) filter, described the kinematic and extended states using the Gaussian and inverse Wishart distributions, respectively. Since introducing the approximation procedure, the relationship between the extended state and the observation noise covariance is controversial, especially when the covariance of observation noise is large. For this reason, several modifications are presented in [25–28] to deal with this problem. In addition to the kinematic and extended states, the measurement rate [33–35] of each target is described using a gamma distribution, under the assumption that the measurement number follows the Poisson distribution. In view of this, the resulting filter, called gamma GIW (GGIW) filter, estimates the kinematic, extended and measurement-rate states simultaneously. Seen from Fig. 1(d), a given number S represents a value of the measurement rate state, which denotes at each time step the number of measurements generated by each target.

However, when the high-resolution sensor is applied or the distance between the sensor and the target is close enough, the spatial distributions of multiple measurements can intuitively reflect the structure information of targets. In this case, the extended states of target cannot be simply approximated as an ellipse and the non-ellipsoidal extended target tracking (NETT) problem arises. The random-hypersurface approach can describe a more complicated extended state, particularly the star-convex shape [36], but many actual extensions may not be described accurately using it, such as aircraft-shape, and T-shape. Hence, a new approach [37], proposed by Lan, considered using several sub-objects to approximate the extended state of the non-ellipsoidal target, which is more reasonable than using a single ellipse. Illustrated in Fig. 1(e), the three sub-objects, using the GIW method, approximate the aircraft shape extended state of target independently. With their centers at different positions, the three sub-objects accurately describe the extended state of non-ellipsoidal target, which is fundamentally different to the single centroid of the random-hypersurface approach. Furthermore, using a single state vector, the unified kinematic version [38], a modification of [37], models the states of several sub-objects independently, see Fig. 1(f). With the GGIW method, [38] estimates the kinematic, extended and measurement-rate states of each sub-object, which shows a superior performance than Lan's approach.

The two approaches for the NETT problem share the same assumption that the number of sub-objects remains unchanged in the whole tracking scenarios. The assumption indicates that the attitude of the target remains still from the sensor view, which is unlikely in real scenarios. When the relative attitude between the target and sensor varies, the view from the sensor on the target may change abruptly. For example, if the aircraft's attitude to the sensor changes from its belly to the head, the target's extended state with three sub-objects transforms to the state with one object. Under this circumstance, the NETT algorithm must be altered to track the non-ellipsoidal extended target with varying number of sub-objects.

In this paper, a filter is proposed, named varying number of sub-objects for non-ellipsoidal extended target tracking gamma Gaussian inverse Wishart (VN-NETT-GGIW) filter, for tracking the maneuvering non-ellipsoidal extended target with varying number of sub-objects and estimating the kinematic, extended and measurement-rate states of each sub-object. Firstly, the established NETT algorithms, introduced by Lan and Granström in [37,38], are presented, and the advantages and disadvantages are analyzed. Then, based on the analyses, the essence of the NETT algorithms is revealed and the possible solutions to the NETT problem with varying number of sub-objects are discussed. Finally, the VN-NETT-GGIW filter is proposed by developing the spawning and combination criterions within sub-objects, which changes the number of applied sub-objects in NETT problem automatically. In the proposed filter, the two forms of maneuvering, the kinematic maneuver-