# Data Fusion Methods for Netted Sensors with Limited Communication Bandwidth

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**Abstract:** This paper considers measurement and track fusion (tracklet) methods for combining sensor data in a military netted sensors context involving a small number of surveillance sensors in which the available communications bandwidth is limited. It is concluded that tracklets methods have potential in netted sensor applications, in particular for sensors with high data rate and/or low measurement dimensionality.

## 1 Introduction

This paper is concerned with the integration of kinematic sensor data in a military netted sensors context that comprises a relatively small number (typically less than 10) of high value surveillance sensors such as radar, infrared search and track (IRST) and electronic support measures (ESM). This sensor suite, which might be deployed on ships, aircraft and at fixed land bases, would be required to survey an area of several thousand square kilometres. This application is quite different to other sensor networks [1] which typically involve a network of several inexpensive, short-range, often passive (e.g. acoustic, seismic, magnetic) sensors for surveillance/security [2].

For netted sensor applications – in which sensors are distributed across multiple, non-collocated platforms – a communications network infrastructure is a usual prerequisite. Generally speaking the wide-ranging demands on a communications network means that any methods that can reduce the bandwidth requirements, whilst ensuring that the broader objectives of a mission can be accomplished, are to be welcomed. This impetus certainly applies to sensor fusion systems irrespective of whether the communications bandwidth is shared by many users or is solely for the distribution of sensor data.

This paper covers some technical issues connected with netted sensor data fusion methods with an emphasis on their communication requirements for different levels of sensor data. The two basic fusion methods are briefly reviewed followed by an account of a "tracklets" technique. These methods are contrasted with respect to their communications load requirements. Conclusions are drawn on the utility of the tracklets method for netted sensors applications.

## 2 Fusion methods

In netted sensors applications there are two predominant methods for the fusion of sensor data, which are commonly [3] referred to as measurement fusion and track fusion, although other terms are used in the literature [4]. In the former method, as depicted in architectural form in Figure 1, sensor measurements are passed to a central fusion point for the generation of composite (multisensor) tracks.

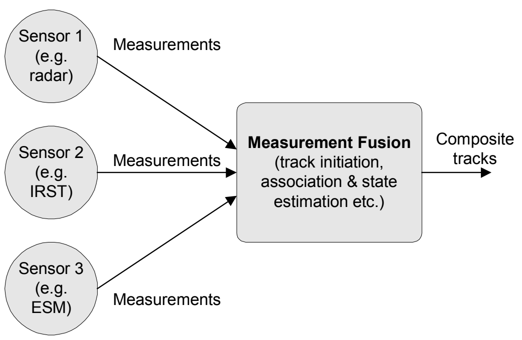


**Figure 1: Measurement fusion processing**

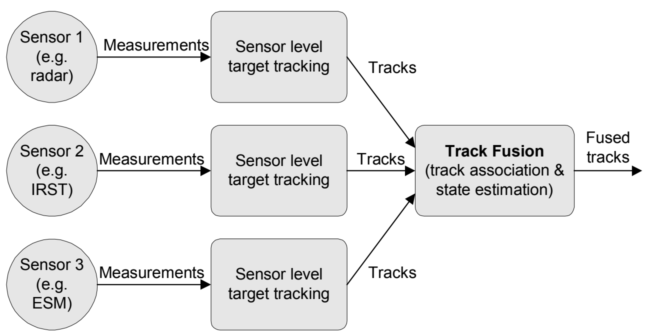


**Figure 2: Track fusion processing**

Usually measurement data are not "fused" as such but are processed sequentially by multisensor track extraction using processing stages such as track initiation, measurement-to-track-association and track maintenance (state estimation). The approach is frequently claimed to offer optimal performance, however, it is often impractical in a network environment involving real sensors that report several false, e.g. clutter, measurements owing to the gross data load that would result. A more practical approach is when associated measurement reports (AMRs) are distributed [4]. This is the case that is considered in the remainder of this paper.

In the second method, shown in Figure 2, sensor-level tracks are combined in a track fusion system using track association/correlation and, normally, state estimation processing. A disadvantage of track fusion is the inherent loss of measurement data early on in the overall sensor fusion processing chain which is not present with measurement fusion. This may not be that significant for practical applications with any disadvantages being counterbalanced by reduced sensitivity to sensor registration errors.

One of the main difficulties with track fusion methods is the correlation that can exist between two tracks that are fused. This topic, which has been researched extensively [4], is typically caused by common process noise introduced by sensor-level tracking filters to accommodate target manoeuvres. Other types of correlation, such as caused by common prior information, are also possible.

The complications of cross-correlation between tracks is side-stepped in some track fusion approaches by calculating the fused track state estimate according to the "best" contributing track [5], which is often based on *a priori* knowledge of the most accurate sensor. In a netted sensors context this mentality also forms the basis of a reporting responsibility type of netted sensor architecture. This method has the attraction of simplicity and low communications bandwidth but has limitations in that it cannot easily exploit the benefits of fusing data from geographically diverse sensors. An alternative approach, which is the focus of the remainder of this paper, is called "tracklets" which could potentially be more useful for netted sensor applications than either measurement fusion or track fusion.

## 3 Tracklets

A tracklet is loosely defined [6] as a track segment whose errors are not cross-correlated with the errors of any other track distributed in a network. A tracklet is essentially an aggregation of a (typically small) number of consecutive sensor reports processed by a sensor-level tracker, and represented as a state vector and covariance. The number of sensor reports that are aggregated into a tracklet defines the tracklet interval [7]. This concept is shown in Figure 3, in which measurements are depicted as black circles. The tracklet interval need not be fixed in a system; indeed it can be variable between tracklets across objects or altered between tracklet reports on a single object. This flexibility provides a level of control such that the rate at which data are passed around a netted sensor system can be adjusted according to particular requirements.

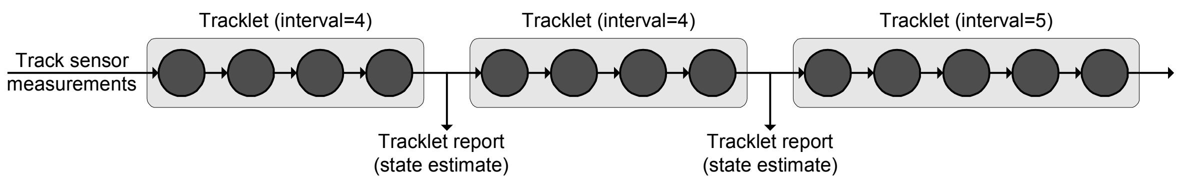


**Figure 3: Tracklet illustration**

Several tracklet variants are available [6], [8], with the most common variant involving the computation of an "equivalent measurement" based on an inverse Kalman filter. The equivalent measurement vector, $u_n$, and error covariance, $U_n$, at time $n$, are formed from data used in the sensor level track since the tracklet was last communicated, at time $m$, as follows:

$$u_n = X_{n|m} + P_{n|m}[P_{n|m} - P_n]^{-1}[X_n - X_{n|m}] \quad (1)$$

$$U_n = P_{n|m}[P_{n|m} - P_n]^{-1} P_n \quad (2)$$

Where:

$X_{n|m}$ and $P_{n|m}$ are the state and covariance of the track(let), last communicated at time *m*, propagated to time *n*; with *n* usually later than *m*.

$X_n$ and $P_n$ are the estimated state and covariance of sensor track at time $n$.

The attraction of the technique is the tracklet (i.e. equivalent measurement, $u_n$, and covariance, $U_n$) can be processed using the standard Kalman filter update equation [4] along with other measurements in a measurement fusion framework.

This tracklet formulation assumes there is no process noise (i.e. target manoeuvre) although extensions exist to accommodate random manoeuvres. Nevertheless the no (or very small) process noise assumption is often not that significant for many targets and for high reporting rate sensors.

The benefit of tracklets in reducing communication load clearly must come at a cost owing to the reduced information content that is passed across a network. This manifests itself as a reduction in track state (i.e. position and velocity) accuracy that will grow in proportion to the interval since the time of the last tracklet report on a target, which will often be dependent on the manoeuvre status of a target. Although high kinematic accuracy is critical for some applications, e.g. for weapon targeting, it is often not essential for general situational awareness on distant targets. It is this inherent ability to adapt the interval between reports that make tracklets an attractive technique for netted sensor applications such as limiting the communication bandwidth during high load conditions.

## 4 Comparison of tracklet and measurement representations

The main distinction in distributing track/tracklet and measurement data in a sensor network is the relative difference in size between state and measurement vectors and their uncertainty (e.g. covariance) representations. Measurements are typically quite compact compared with track state estimates and can be distributed more often for the same overall communications load. Table 1 contrasts typical track and measurement message requirements for radar, IRST and ESM sensors as representative of 3D, 2D and 1D sensors respectively. The symmetrical properties of error covariance matrices have been assumed in the presentation of these figures and that sensor location/navigation information, if required, is distributed separately in less frequent message transmissions. These figures are indicative only and more efficient use of the bits in a word might be possible for certain applications in which aspects of the uncertainty representation could be eliminated altogether.

| | **Number of words required for parameter representation** | | | | |
|---|---|---|---|---|---|
| **Sensor** | Kinematics (X, Y etc.) | Uncertainty ($\sigma_X^2$,$\sigma_Y^2$ etc.) | Time | Track no. | Total (words) |
| Radar | | | | | |
| Measurement | 3 | 3 | 1 | 0 | 7 |
| Tracklet | 6 | 21 | 1 | 1 | 29 |
| IRST | | | | | |
| Measurement | 2 | 2 | 1 | 0 | 5 |
| Tracklet | 4 | 10 | 1 | 1 | 16 |
| ESM | | | | | |
| Measurement | 1 | 1 | 1 | 0 | 3 |
| Tracklet | 2 | 3 | 1 | 1 | 7 |

**Table 1: Comparison of typical measurement and tracklet message sizes for common sensors**

The conclusion from this analysis is that the size efficiency of measurements compared with tracklets, in terms of communication bandwidth requirements, increases with sensor measurement dimension. For tracklets to offer any communications benefit compared with measurement fusion (i.e. AMRs), in the case of radar, then at least 4 measurements need to be accumulated into a tracklet, prior to distribution throughout the network. The minimum tracklet interval for passive sensor data to realise communication efficiency is reduced (approximately to 2 or 3) owing principally to the more condensed error representation.

Therefore the greatest potential gains to be achieved in using tracklets – in terms of saving communications load – are with high data rate sensors of low measurement dimension. In the application area considered in this paper it relates to ESM and IRST sensors. This is rather pleasing since these sensors would be more likely to require a sensor level tracking function appropriate for adaptation to tracklet type processing.

## 5 Conclusions

The choice between distributing measurement and track data in netted sensor applications is complicated by the competing demands of tracking performance (accuracy, completeness, continuity etc.) and reducing communications load. Recent interest in tracklets, which are like tracks (but with properties similar to measurements), could afford benefits for netted sensor applications where communications bandwidth is limited. These techniques, which have received mixed coverage in the literature, merit further study since they may provide a flexible solution to many netted sensors applications that are subject to bandwidth constraints. This aspect of tracklets does not appear to have been adequately covered in the literature particularly for high data rate sensors, with low measurement dimensionality, which is the application area that should provide the greatest scope for saving communications load.

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