Comparison of plot and track fusion for naval sensor integration

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Abstract - *This paper compares plot and track fusion for a generic suite of sensors that might be available on a future warship, with an emphasis on their relative ability to maintain track continuity in the event of missed measurements/plots. Using plot fusion measurement level data are formed into tracks at a central location, whereas with track fusion state estimate (i.e. track) level data are combined from separate sensors into a single track state estimate. An extensive amount of literature discusses the two methods from an architectural standpoint although few quantitative results exist on the advantages and disadvantages of the two approaches for practical sensor integration applications. Results are presented for parametric modelling of track continuity and track completeness based on analysis of naval radar data characteristics.*

Keywords: Plot fusion, track fusion, sensor integration.

1 Introduction

Multisensor integration systems concerned with the estimation of an object's kinematic parameters normally adopt either a plot[1] fusion (PF) or track fusion (TF) architecture, or in some cases a combination of both. The two basic architectures are the more common names, in the maritime community, for sensor-level tracking and central-level tracking respectively [1,2,3].

1.1 Plot fusion

The key feature of the plot fusion architecture, depicted in its simplest form in Figure 1, is that all plots (targets, clutter, noise etc.) from each contributing sensor are passed to a central tracker for track initiation, track maintenance and track deletion. A design in which all measurements are transmitted to a central tracker is often considered idealised or "pure" plot fusion which, although conceptually simple, has some potential limitations for real applications. These include high data load and susceptibility to false track generation which often give rise to hybrid, or practical plot fusion variants. Generally speaking with practical plot fusion, each contributing sensor incorporates a dedicated tracker to pre-filter the data with the aim that only plots likely to pertain to objects of interest are passed to the central tracker.

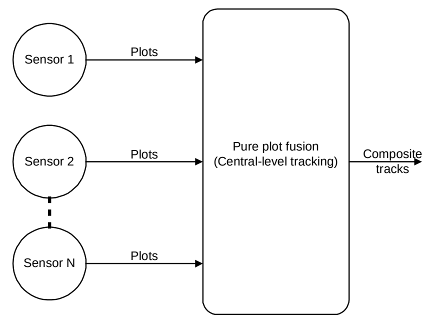

Figure 1. Pure plot fusion architecture.

1.2 Track fusion

With track fusion, shown in Figure 2, each contributing sensor includes local track extraction processing that supplies track (i.e. state estimate and covariance) data to a central fusion location. Track fusion, in which multiple sensor tracks are then formed using track-to-track association logic, can be implemented in several different ways. For example feedback from the fusion centre, to assist individual sensor level tracking, may be advantageous in some applications [1].

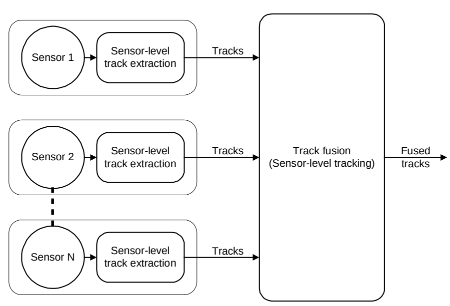

Figure 2. Track fusion architecture

[1] Also known as measurement, contact, hit.

Another approach sometimes used in real systems is to only report the best provider track as the fused track. This technique can be less susceptible to data incest in complex systems.

A more complete description of the two (plot fusion and track fusion) architectures, using more generalised terminology, is available in the literature [1,2] including some suggestions that plot fusion is to be favoured over track fusion, although few quantitative results on the merits of the two approaches are generally provided.

The aim of this paper is to quantify the benefits (or otherwise) of plot fusion in maintaining track continuity. Track continuity relates to the chance that a track will be lost following a sequence of missed looks. Its practical significance is often apparent with radar tracking in conditions that favour multipath lobing [4]. In calm sea conditions the propagation nulls can cause a significant drop in P_d, and aircraft overflying the radar at medium to high altitude will fly through many such nulls with the consequent possibility that their tracks will be fragmented. Propagation nulls, through destructive interference due to ground or sea reflections of a transponder signal, can also affect the returns from a secondary surveillance radar (SSR). A tracking system with good continuity can help maintain tracks through these periods of intermittent detections, which is a strong factor in maintaining track identity (ID).

1.3 Method of comparison

The comparison of plot fusion and track fusion comprised the following 4 stages:

1. Analysis of real radar data to ascertain track discontinuities,
2. Construction of a parametric model,
3. Use of real data characteristics in setting the model,
4. Simulation to obtain results for track continuity and track completeness comparison of PF and TF.

2 Assessment of track discontinuities

Track data from real trials recordings of shipboard radars have been examined to assess the extent of track breaks and their causes. The purpose of this is to make the modelling of track discontinuities representative of real sensor performance. To assess the extent to which discontinuities in tracks from one sensor correspond to discontinuities in tracks from another some simultaneously recorded track data from 5 track extractors, from primary and secondary radars, have been examined. The data assessed cover just over 1 hour of trials time.

2.1 Analysis of sensor recordings

A subset of tracks, that represent the principal targets in the hour scenario, have been isolated in order to assess the underlying reason for track loss. The main targets, that have be reconstructed from the sensor output using semi-automated analysis, are depicted in plan view in Figure 3. The square attached to each track represents the start position whereas the assigned track number is shown at the tail of each track.

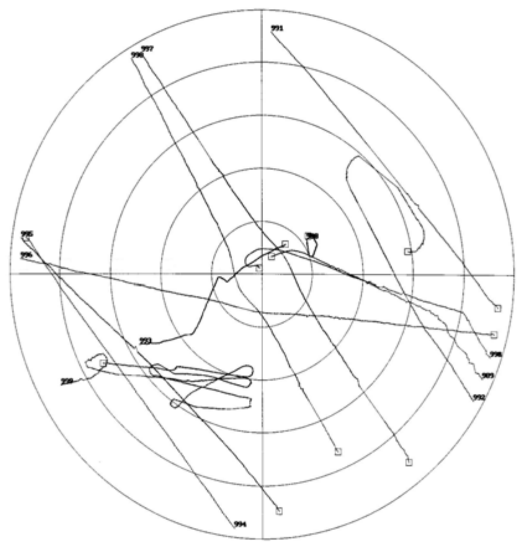

Figure 3. Plot sequence history of 12 reference targets.

The target tracks shown are a mixture of different types and each is in view for a considerable period, summarised in Table 1, which enables them to be used as a reference against which the extent of track discontinuities with each sensor can be assessed.

Table 1. Details of reference targets.

Target	Duration (s)	Type
999	3508	Helicopter
998	950	Commercial a/c
997	1108	Commercial a/c
996	950	Commercial a/c
995	1124	Light a/c
994	596	Commercial a/c
993	1517	Helicopter
992	1101	Military a/c
991	702	Commercial a/c
990	671	Military a/c
989	499	Military a/c
988	2001	Ship

Figure 4 shows track level output from a primary radar system, hereafter referred to as radar A, and indicates some track fragmentation caused by numerous phenomenological and other systematic effects typical of real systems. Original track numbers are illustrated alongside each track.

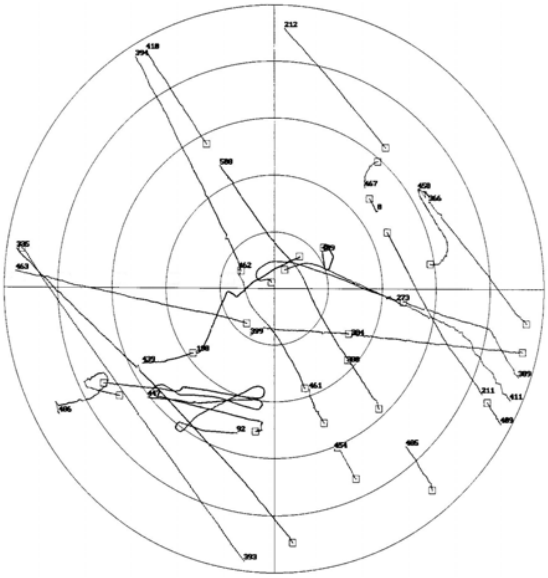

Figure 4. Radar A tracks corresponding to reference targets.

Figure 5 shows the tracks from a further primary radar, termed radar B, corresponding to the reference targets. The lack of tracks close to own ship is partly indicative of a relatively narrow elevation beamwidth typical of some classes of radar.

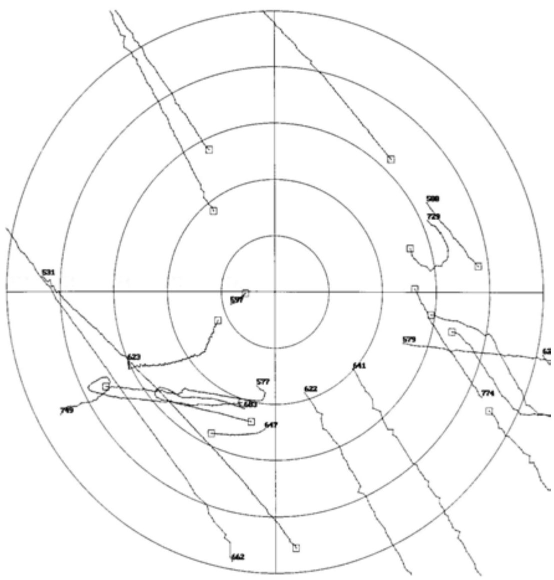

Figure 5. Radar B tracks corresponding to reference targets

2.2 Modelling implications

The track data for the two radars illustrate many of the potential causes of track loss or absence with real sensors. These include:

- Slow initiation caused by low Pd and/or high clutter
- Low Pd, including during propagation nulls
- Track seduction by clutter or another target
- Missed association during target manoeuvre
- Target outside sensor coverage
- Geographical masking

The track pictures also illustrate that the onset of track loss with one tracker does not typically correspond to track loss with another. However there are clearly some potential causes of breaks (e.g. geographical masking) that are certain to affect both, and others that might affect both to a varying degree (e.g. land clutter, even though that will not affect SSR). But overall the observed and potential scope for correlation appears slight and its inclusion would not seem to significantly add to the realism of any modelling of track loss. This pattern has also been observed for other sensor combinations.

Three generic types of track dicontinuity can be considered to capture the potential causes of track loss. These are:

Simple break	track ends, but reinitialisation begins immediately with no change in Pd,
Gap	no plots at all for a prescribed period, resulting in track loss and possibly some considerable delay before the track is reinitialised,
Fade	target has reduced Pd for a prescribed period; this is a factor in the track being lost and may considerably delay its reinitialisation.

For the two sets of radar track data, illustrated in Figures 4 and 5, the generic types of track loss have been assessed together with parameters such as average track lifetime and the fraction of track lost. The average time between breaks has been assessed by dividing the total life of the reference targets (Table 1) by the total number of breaks. The fraction of track lost has been estimated from the total duration of the tracks compared with the reference targets. The breakdown of gaps, breaks and fades is shown in Table 2, whereas the average track lifetime, that takes account of the lost track fraction as well as the number of breaks, are shown in Table 3. These are presented as a precursor to a description of a simulation based on these real sensor characteristics, together with results.

Table 2. Track loss statistics based on reference targets.

Radar tracker	Occurrences of different types of track loss			
	Break	Gap	fade	Total
A	6	0	13	19
B	3	4	12	19

Table 3. Track loss statistics based on reference targets

Radar tracker	Av. time Between breaks (s)	Lost fraction of track	Average track lifetime (s)
A	760	0.15	680
B	760	0.25	570

3 Simulation method

A Monte Carlo simulation of the plot occurrences from two sensors has been adopted. Rules for track formation and deletion determine when a target is notionally tracked and enable track loss statistics to be accumulated for single sensor tracking, track fusion and plot fusion. For plot fusion, the same track initiation and deletion rules apply as for a single sensor. The simulation determines stochastically whether a plot is received at the due time, and the occurrence of breaks, gaps and fades, the duration of gaps and fades, and the choice of *Pd* within each fade. It should be noted that the modelling only simulates the occurrence of plots and not the plot parameters as these are not directly relevant to the existence or absence of a track.

3.1 Input data

The input data determine the overall proportion of lost track and the relative occurrences of each type of break. For each sensor the parameters that can be controlled are

τ sensor revisit interval

Pd a value applicable to normal tracking

L fraction of lost track

T_L average track lifetime

b, g, f relative proportions of breaks, gaps and fades.

In addition parameters determining track initiation and track deletion, independent of sensor, also provide input to the simulation. Track initiation is according to *m/n* cascaded logic [5]. Tracks are deleted after a specified plot-free time T_D.

3.2 Probability calculations

If ρ denotes a random number drawn on (0,1) then different realisations of ρ are compared with

Pd to determine if a plot is received,

$\tau/T_L(1-L)$ to determine if a track break is due,

b, *g* and *f* to determine the type of track break,

τ/T_f to determine if an existing gap or fade is due to end.

Where T_f is the desired mean length of a fade which is discussed below.

These tests to determine the onset and duration of breaks constitute repeated Bernoulli trials, and a binomial distribution therefore governs the onset and duration of breaks, with mean times T_L and T_f as required. If *p* is the probability associated with a track break event, then the probability that the event occurs (for the first time) by scan *n* is $1 - (1-p)^n$.

3.3 Treatment of target fades

If T_b, T_g and T_f denote the specified average length of simple breaks, gaps and fades respectively, then the lost track fraction, *L*, will be

$$L = \frac{bT_b + gT_g + fT_f}{T_L} \quad (1)$$

If the average length of a lost track is assumed to be the same length as a track fade then T_f can be determined from the input data according to

$$T_f = \frac{LT_L - bT_b}{(g+f)} \quad (2)$$

T_b does not require specification since track reinitiation following a simple break occurs automatically according to the hit/miss sequence, but an estimate of T_b is required in order to calculate T_f

$$T_b = \tau\left(\frac{N+1}{2}\right)\left(\frac{1}{Pd}\right)^2 \quad (3)$$

Where *N* is the track confirmation threshold required for the *m/n* initiation rule. Setting N to 5 or 7 is equivalent to confirmation requiring 3 out of 4, or 4 out of 5 plots respectively. To enhance the chance of a track becoming lost during the fade, *Pd* is reduced by a random amount to $Pd = \rho\tau/T_D$ where T_D, the deletion time, is itself halved, which is appropriate since tracks will be deleted more rapidly in cluttered conditions.

4 Results

4.1 Relating to track initiation method

As introduced above there are several potential methods of implementing plot fusion and hybrid variants are generally favoured in the recent literature [2]. One variation of the hybrid fusion approach is to adopt single sensor track formation and multisensor track updating. In order to test whether this choice impacts track completeness in fade-free scenarios, sensors with approximately 4s and 2s revisit intervals have been simulated. Tracks are initiated using an any 4 from 5 plot opportunities rule and deleted after 24s without a plot. Pd values between 0.3 and 0.6 were used and each case was run for 10^7s, which is equivalent to 100 targets being tracked for 24 hours.

The results in Table 4 show that the choice of track initiation method makes no significant difference to track completeness. The only significant difference to track initiation time occurs at high Pd, while at low Pd the initiation times converge asymptotically to half the average single sensor track initiation times. At Pd $\geq$ 0.6 hardly any track breaks occur (with a 2s sensor there is a very slim chance of getting 12 consecutive missed measurements) and therefore hardly any restarts. At Pd = 0.3 there are around 2,500 breaks, but the few seconds advantage that multisensor initiation should on average give, make a negligible difference to the total lost track time (~ 2.10^5s). As a result of there being no disadvantage in this constant Pd case, the remaining results presented in this paper have been obtained using plot fusion with single sensor track initiation.

Table 4. Comparison of multisensor and single sensor track initiation

Fusion method	Percentage (%) of missed track			
Pd	0.6	0.5	0.4	0.3
Plot fusion with multisensor initiation	0.0003	0.0010	0.0786	1.9357
Plot fusion with single sensor initiation	0.0001	0.0025	0.0822	1.9023
Track fusion	0.0002	0.0071	0.3307	8.3282

4.2 Parametric studies with similar sensors

The simulation has been run for two identical sensors using input parameters based on the average of the two sensors whose track continuity was assessed in section 2. This enables the relative benefits of track and plot fusion to be assessed for a broad range of lost track fractions. The relative proportion of breaks, gaps and fades has been accordingly set to 0.25, 0.1 and 0.65 respectively. A scan period of 5s has been used for the simulation which is fairly typical of modern naval surveillance radar systems, together with a 4-out-of-5 track initiation rule and average *Pd* of 0.8. The results for average track duration (i.e. track continuity) and percentage of missing track (i.e. track completeness) are given in Tables 5 and 6 below for an average proportion of lost track, *L*, varied from 10 to 50%.

Table 5. Track duration v nominal lost track fraction.

Lost track fraction	Mean track duration (s)		PF/TF advantage factor
	Track fusion	Plot fusion	
0.10	4436	18827	4.24
0.15	2468	8663	3.51
0.20	1629	5160	3.17
0.30	843	2500	2.97
0.40	501	1427	2.85
0.50	309	889	2.87

Table 6. Missing track v nominal lost track fraction

Lost track fraction	Missing track %		PF/TF advantage factor
	Track fusion	Plot fusion	
0.10	0.953	0.405	2.35
0.15	2.13	1.06	2.00
0.20	3.69	2.01	1.84
0.30	8.31	4.92	1.69
0.40	14.72	9.14	1.61
0.50	22.92	14.56	1.57

The key feature of the results is that the advantage that plot fusion has over track fusion decreases as the fraction of lost track increases. Increasing the notional track lifetime in the input data, which has the effect of producing fewer but longer fades, gives a similar set of results, except that the advantage of plot fusion is reduced even further.

The results indicate that the advantage of plot fusion, in maintaining track during periods of reduced Pd, is curtailed (a) when Pd is significantly reduced, and (b) as the average length of fades increases. If the proportion of gaps to fades is reversed then this further accentuates this effect, and the PF/TF advantage factors with this same case reduce to approximately unity for track duration and missing track respectively. Clearly if there are no plots at all from a sensor over a protracted period then the fusion method is irrelevant. Conversely, if the fades are made wider but shallower (i.e. longer duration but less reduction in Pd) then the plot fusion advantage increases quite significantly. The results also reveal that the advantage factor that either form of fusion has over single sensor tracking diminishes quite noticeably as the proportion of missed track increases.

5 Conclusions

It is concluded that plot fusion has advantages compared with track fusion for track continuity and track completeness, and is most advantageous when plots are sparsely drawn from a uniform distribution, but least advantageous when the plot streams are interrupted with complete gaps. The results from the simulations for realistic sensor parameters indicate that plot fusion provides an advantage factor of approximately 1½ to 2½ for reducing the number of untracked plots associated with real targets, and an advantage factor of between 2½ to 4½ with respect to average track length. The number of tracks generated will be reduced by a similar factor and this could be a considerable element in helping to present operators with a less confusing picture. Both forms of fusion offer significant advantages over single sensor tracking.

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