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A Method For Track Fusing using Data Association in Naval Combat System

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1. INTRODUCTION

➢ Title: A Method For Track Fusing using Data Association in Naval Combat System

**Background**

- **Naval Combat Management System (CMS)'s role**
  - CMS plays a role as brain of battle ship by monitoring battlefield, executing threat evaluation of detected tracks to help command decision of commander, acting to threat tracks.

- **The reason of track fusion in CMS**
  - The tracks are detected by multi-sensors or tactical data communication that are mounted on ship. For this reason, CMS has been required a technique for fusion tracks that are determined same target from each sensor.

- **Sensor development**
  - A track fusing technique has been further important today because the quality of target information is higher and the quantity is larger than old one according to growing the sensor capability.

- **Mission type change**
  - According to changing mission type at solo to join. CMS is required the ability to provide track information to other.
1. INTRODUCTION

➢ Title: A Method For Track Fusing using Data Association in Naval Combat System

Outline

▪ Track Management(TM) of CMS
  - Track management is one of the main data processing algorithms of the CMS. This has the functions to process and fuse incoming data from multi-sensors and communication systems.

▪ Data Association(Tracking Filter)
  - In clutter environment, data association method is to predict and estimate of target state every scan time based on stochastic model. At this time the target has to be located within validation area that it is made by target state variable(prediction and update).

▪ Track Fusion method suggestion using Validation Gate
  - The validation gate is an area having a probability of presence of target. It’s concept is applied to track fusion and defusion condition. So to fuse between tracks considers track attributes(ID, category, form ..etc.), position and maneuver information.
2. MAIN SUBJECT

Combat Management System (CMS)

- Operational concept diagram

<table>
<thead>
<tr>
<th>Warfare type</th>
<th>AAW</th>
<th>ASuW</th>
<th>ASW</th>
<th>EW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Command control</td>
<td>Tactical Data Management</td>
<td>Command decision support</td>
<td>Threat evaluation</td>
<td>Tactical situation monitoring</td>
</tr>
<tr>
<td>Weapon control</td>
<td>Mounted weapon monitoring and fire control</td>
<td>Weapon assignment</td>
<td>Engagement evaluation</td>
<td></td>
</tr>
</tbody>
</table>
2. MAIN SUBJECT

The function of the CMS

Detection/Tracking Sensor
- Surveillance radar
- Tracking radar
- EOTS
- ESM
- IFF
- HMS

Tactical Communications
- Data Link
- Integrated communication system

Weapon
- DECOY
- ECM
- GUN
- SAAM
- CIWS
- SSM
- TORPEDO
- TACM

Battlefield Monitoring

Target Detection/Identification

Command Decision

Engagement

Sensor control

Weapon control

Track management

Firing data calculation

Threat evaluation

Engagement control

Threat evaluation

Sensor control

Weapon control

Track management

Firing data calculation

□ EOTS : Electro-Optical Targeting System
□ IFF : Identification Friend or Foe
□ ESM : Electronic Support Measure
□ HMS : Hull Mounted Sonar
□ ECM : Electronic Counter Measure
□ SAAM : Surface to Air Anti Missile
□ CIWS : Close-In Weapon System
□ SSM : Surface to Surface Missile
□ TACM : Torpedo Acoustic Counter Measure
## 2. MAIN SUBJECT

### Track Management(TM) of CMS

#### The function of TM

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>DETAILED</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track data management</td>
<td>Track creation/update/deletion</td>
<td>Source track/System track/ Tactical track data management</td>
</tr>
<tr>
<td></td>
<td>Fusion/Defusion</td>
<td>For making system(or tactical track) by applying the logic</td>
</tr>
<tr>
<td></td>
<td>Correlation/Decorrelation</td>
<td></td>
</tr>
<tr>
<td>Tactical support</td>
<td>Association/Dissociation</td>
<td>The tactical relationship between tracks</td>
</tr>
<tr>
<td></td>
<td>Pairing/Depairing</td>
<td></td>
</tr>
<tr>
<td>Track identification</td>
<td>IFF code management</td>
<td>IFF code from operator for identifying track ID</td>
</tr>
<tr>
<td></td>
<td>Track ID decision</td>
<td>Track ID is decided by matching between codes from IFF and operator</td>
</tr>
</tbody>
</table>

※Track ID : friend, assumed friend, neutral, suspect, hostile, unknown
2. MAIN SUBJECT

Procedure of Track Management

- Target detection
- Fusion / Defusion

- Data link
- System track
- Network track
- Correlation / Decorrelation

- Tactical track
- Association / Dissociation
- Pairing / Depairing
2. MAIN SUBJECT

Track Fusion

- **Purpose**
  To create a track (system track & tactical track) from the source tracks of each sensor

- **Why is created fused track?**
  Because tactical activity is operated based on the fused track (tactical track)

- **How to**
  When the new source track is created, by determining as same track using attributes of track after fusion, the tactical track information is updated according to update of source track
  But at the same time, when fused track is judged that is same track no longer, the defusion could take a place
2. MAIN SUBJECT

The composition of Tactical track

Basic information

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track number</td>
<td>Track unique identifier</td>
</tr>
<tr>
<td>Position</td>
<td>latitude, longitude, altitude, bearing, elevation, range</td>
</tr>
<tr>
<td>Maneuver information</td>
<td>course, velocity</td>
</tr>
<tr>
<td>Track category</td>
<td>Air, Surface, Subsurface, Land, Unknown</td>
</tr>
<tr>
<td>Track type</td>
<td>Point track, bearing track</td>
</tr>
<tr>
<td>Track identification</td>
<td>unknown, assumed friend, friend, neutral, suspect, hostile, pending</td>
</tr>
</tbody>
</table>

Additional information for tactical activity

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engagement status</td>
<td>no-engagement, engagement, target direction</td>
</tr>
<tr>
<td>Engagement result</td>
<td>unknown, hit, fail</td>
</tr>
<tr>
<td>Weapon max. effective range</td>
<td>maximum effective range of weapon what loaded this target</td>
</tr>
<tr>
<td>ESM info</td>
<td>characteristic information what are acquired from ESM</td>
</tr>
<tr>
<td>IFF info</td>
<td>code information what are acquired from IFF</td>
</tr>
</tbody>
</table>
2. MAIN SUBJECT

Suggestion of Track fusion

- **Start**
  - **Point tracks?**
    - yes
    - **Different type sensor?**
      - no
      - yes
      - **Same category?**
        - no
        - yes
        - **Same type?**
          - no
          - yes
          - **ID conflict?**
            - yes
            - **Is track located inside of the validation area?**
              - no
              - yes
              - **Fusion possible**
              - no
              - **Fusion impossible**

※ Track ID: friend, assumed friend, neutral, suspect, hostile, unknown
※ Category: Air, Surface, Subsurface, Land, Unknown
※ Type: Point track, Bearing track

Sensor#1 measurement
Sensor#2 measurement

Validation area

T+3 T+2 T+1 T
2. MAIN SUBJECT

Suggestion of Track defusion

- Track ID: friend, assumed friend, neutral, suspect, hostile, unknown
- Category: Air, Surface, Subsurface, Land, Unknown
- Type: Point track, Bearing track

Start

Point tracks?

- yes
  - Is track located outside of the validation area?
    - no
    - Defusion possible
    - yes
      - ID conflict?
        - no
        - Defusion impossible
        - yes
          - Defusion possible

Validation area

Sensor#1 measurement
Sensor#2 measurement

- T+3
- T+2
- T+1
- T

※ Track ID: friend, assumed friend, neutral, suspect, hostile, unknown
※ Category: Air, Surface, Subsurface, Land, Unknown
※ type: Point track, Bearing track
2. MAIN SUBJECT

The validation area in data association

- **Data association**
  Dynamic filtering method based on *Kalman filter*
  In clutter environment, data association method is to predict and estimate of target state every time using the measurements that are located within validation area.

- **Kalman Filter**
  Kalman filter is an algorithm that uses a series of measurements observed over time, containing noise and other inaccuracies, and produces estimates of unknown variables that tend to be more precise than those based on a single measurement alone.

### Recursive structure

\[
\begin{align*}
\hat{X}_k &= \phi_k \hat{X}_{k-1} \\
\hat{P}_k &= \phi_k \hat{P}_{k-1} \phi_k^T + Q_k \\
K_k &= \hat{P}_k H_k^T (H_k \hat{P}_k H_k^T - R_k)^{-1} \\
\hat{X}_k &= \hat{X}_k + K_k (z_k - H_k \hat{X}_k) \\
\hat{P}_k &= (I - K_k H_k) \hat{P}_k
\end{align*}
\]

- \( \hat{X}_k \): a state variable (including position, velocity and acceleration) at \( k \)
- \( \hat{P}_k \): an error covariance matrix at \( k \)
2. MAIN SUBJECT

The validation area in data association

- Validation area
  The validation area is having a probability of presence of target. It is generated on the basis of estimated state variable by the tracking filter.

\[ z_{k,n} : \text{n-th Measurement of } k \]
\[ \bar{X}_k : \text{Predicted state value of } k \text{ based on updated state value of } k-1 \]
2. MAIN SUBJECT

The validation area in data association

- **Validation area**
  The validation area is having a probability of presence of target. It is generated on the basis of estimated state variable by the tracking filter.

- Validation area is created with predicted position as the center and predicted position is calculated by dynamic filter

\[ G_{\gamma}(k) = \{ v_k \mid v_k^T S_k^{-1} v_k \leq \gamma \} \]

- The volume of Validation area

\[ V_G = \frac{1}{2} \frac{1}{n} \frac{n}{C_1} \frac{n}{C_2} \frac{n}{C_3} \gamma^2 \]

\[ C_1 = 2, C_2 = \pi, C_3 = \frac{4}{3} \pi \]

\[ S_k = H_k P_k H_k^T + R \]
2. MAIN SUBJECT

The validation area simulation example

- 2-D model

<table>
<thead>
<tr>
<th>The initial position</th>
<th>(+15000m,+15000m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The initial velocity</td>
<td>(-70.71m/s,-70.71m/s)</td>
</tr>
<tr>
<td>And then 20 second will start up in the other direction</td>
<td></td>
</tr>
<tr>
<td>Sampling time</td>
<td>1sec</td>
</tr>
<tr>
<td>Measurement error</td>
<td>$v_x \sim N(0,(15m)^2)$</td>
</tr>
<tr>
<td></td>
<td>$v_y \sim N(0,(15m)^2)$</td>
</tr>
<tr>
<td>Used filter</td>
<td>Kalman filter</td>
</tr>
</tbody>
</table>

Because of increasing of difference between measured position and predicted position by unexpected turn, the validation area was expended.
2. MAIN SUBJECT

The data association

3 type of data association (according to used track information)

- **Type of NN**
  - Nearest Neighbor: Considered as a target the closest measurement to the center of the validation area
    1. NNF (Nearest Neighbor Filter)
    2. PNNF (Probabilistic Nearest Neighbor Filter)
    3. PNNF-m (PNNF with m validated measurement)

- **Type of SN**
  - Strongest Neighbor: Considered as a target the measurement that have a greatest signal strength in the validation area
    1. SNF (Strongest Neighbor Filter)
    2. PSNF (Probabilistic Strongest Neighbor Filter)
    3. PSNF-m (PSNF with m validated measurement)

- **Type of PDA**
  - Probabilistic Data Association: Considered as a target that have a highest probability that comes from real target. In this filters, both signal and distance are considered.
    1. PDA (Probabilistic Data Association)
    2. MPDA (Most Probable Data Association)
    3. HPDA (Highest Probability Data Association)
3. CONCLUSION

**Summary & Conclusion**

- **New Method of Track Fusion using Validation Gate**
  - The method is to apply the validation area of data association. Making the validation area is adaptive because it reflects the current situation of the target. So this method using data association may be useful because the consideration target of the current battlefield status.

- **Need to robust Tracking Filter**
  - But if prediction and estimation of track are failed, wrong validation area is made also. Therefore, robust tracking performance is required.

- **The other requirement for Track Management**
  - The time between the sensors has to be Synchronized because acquisition cycle is different.
  - Operational time of the tracking filter should be considered when maximum tracks are tracked by filter because the tracking filter is one per track.

- **In Future**
  - The applicability of the tactical element and other information of track to improve the fusion accuracy.
    (e.g. formation flying)
Q&A