Evasive Area of Ships in Tokyo bay

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1.1 Distance to Stopping Point

Distance to Stopping Point

Distance

\[ \begin{align*}
20\text{km/h} &
\quad 40\text{km/h} &
\quad 60\text{km/h} &
\quad 100\text{km/h} \\
0 &
\quad 20 &
\quad 40 &
\quad 60 &
\quad 80 &
\quad 100 &
\quad 120 \\
\end{align*} \]

1.2 Maneuvering of avoid to target ship

\[ \begin{align*}
R & : \text{Distance to target ship} \\
VR & : \text{Relative speed} \\
\Theta & : \text{Relative bearing} \\
Ro & : \text{Distance to start to avoid to target ship} \\
m0 & : \text{DCPA (Distance of Closest Point of Approach)} \\
T0 & : \text{TCPA (Time to Closest Point of Approach)} \\
\end{align*} \]
Bumper model

- Ship’s are keeping a distance to other ship (Ships have a bumper that determined by ship’s length)
- Usual bumper size is ellipse (1.6L, 6.4L) and circle (6.4L)

2.1 Marine traffic data

Marine traffic in Tokyo bay
- Well known to be one of the most congested marine traffic areas over the world.
- Number of ships navigating in/out or inside the bay: over 1000 ships per day.
- Mean highest number: over 100 ships.

The close observation is of great importance for preventing collision, protecting environment as well as more efficient traffic service.
2.2 Marine traffic observing system

Marine traffic observing system
- Radar stations: Yokosuka and Kawasaki stations.
- AIS receiver: Installed at Kawasaki station.

Data are received, transferred to and saved at the Server in TUMSAT.

2.3 Research area

- Introducing a method for better automatic tracking of target movement from Radar Images
- Applying Kalman Filter to rebuild target speed and course for traffic analyzing
2.4 An approach for Automatic Radar Tracking

• Principle
• Automatic Tracking without AIS-data
• Automatic Tracking with AIS data

2.4.1 Principle

Set of image positions:
- x, y center coordination
- number of illuminated pixel (pixel number)
- A matrix saving illumination of all pixel in pos.
2.4.2 Automatic Tracking without AIS-data

- Relating-Function for defining and tracking moving targets
- Observation of Radar Targets in Tokyo bay
- Track moving targets
- Track possible overlapping couples
- Tracking result

\[
R = d_{adj} + f \cdot S_{adj} + \cos(180 - \psi)
\]

\[
d_2 \leq d_i \Rightarrow d_{adj} = \frac{d_i}{d_2} - 1
\]

\[
d_2 > d_i \Rightarrow d_{adj} = \frac{d_i}{d_2} - 1
\]

\[
2S_i > S_i + S_j \Rightarrow S_{adj} = \frac{2S_i}{S_i + S_j} - 1
\]

\[
2S_i \leq S_i + S_j \Rightarrow S_{adj} = \frac{S_i + S_j}{2S_i} - 1
\]

Where:
- \(d\): distance between positions
- \(S\): number of pixels in image position, representing the size of this image position.
- \(f\): weight factor

Relating-Function
Observation of Radar Target

\[ R = d_{\text{ref}} + f \cdot S_{\text{ref}} + \cos(180 - \psi) \]
Observation of Radar Target

\[ R = d_{mf} + f \cdot S_{mf} + \cos(180 - \psi) \]

- The choice of ratio factor to be 0.3 in the Relating Function appears to be suitable.
- Threshold values have been set to be:
  
  \[ R1 = -0.85 \text{ for defining the existence of a moving target} \]
  
  \[ R2 = -0.6 \text{ for continuous tracking of that target} \]

Track Moving Targets

Moving target

Pos set from image

Get possible positions set

Possible positions set

Check with R-Function

New position for target

Image positions at t

Position2 at t-2

Position3 at t-1

Position2 at t-3

Position1 at t-4

Position3 at t-2

Target losing position at t-1

Lost position at t-1
Track Possible Overlapping Couples

Target 1
Pos. at t-2
Pos. at t-1
Target 2
Pos. at t-1
Pos. at t-2

Image Positions at t

Target 1 Dead
Reckoning

Target 2 Overlapping position at t
Target 2 Dead
Reckoning

Track Possible Overlapping Couples

Target 1 Dead
Reckoning

Target 2 Dead
Reckoning

Overlapping position at t
2.4.3 Automatic Tracking with AIS-data

- AIS-Radar Target
- Modified Relating Function
- Observation of Radar images for Targets with AIS
- Track AIS-Radar Target
- Tracking Result
AIS-Radar Targets

AIS Database

Radar Targets

AIS-Radar Matching

AIS-Radar Target

AIS-Radar Target: Target tracked from radar image and matched with its equivalent AIS-Data

Modified Relating-Function

\[ R = d_{mdf} + f \cdot S_{mdf} + \cos(180 - \psi) \]

\[
\begin{align*}
  d_2 \leq d & \Rightarrow \frac{d_2}{d} - 1 \\
  d_2 > d & \Rightarrow \frac{d_2}{d} - 1
\end{align*}
\]

\[ d \equiv \text{AIS}_\text{SOG} \cdot \Delta t \]

Where:
- AIS_SOG: target moving speed received from AIS-receiver.
- AIS_COG: target course over ground received from AIS-receiver.
Track AIS-Radar Target

AIS-Radar target → Pos set from image

→ Get possible positions set
→ Possible positions set
→ Check with R-Function
→ New position for target

Image position at t

Pos2 at t-2
Pos3 at t-1

AIS-SOG

AIS-COG

AIS-Radar Target Overlapping Case

Image position at t

Pos2 at t-2
Pos3 at t-1

AIS-COG

AIS-SOG
Tracking Results

Fig. AIS-Radar targets tracking result

Estimated ship’s length from radar image

\[ y = 0.0035x^2 + 0.2327x + 44.594 \]

\[ y = 27.184x - 10.329 \]
3.1 Apply Kalman Filter to Rebuild Target Movement

- Kalman Filter fundamentals
- State space equations for Target Movement
- Determine designing parameter from simulation data
- Filtering Result
### 3.2 Kalman Filter Fundamentals

State space equation of a system

\[
X_k = A \times X_{k-1} + B \times U_k + W_{k-1} \\
Z_k = H \times X_{k-1} + V_k
\]

(1)

where

\[
p(W) \sim N(0, Q) \\
p(V) \sim N(0, R)
\]

Q = E[WW^T] \quad (3)

R = E[VV^T] \quad (4)

### 3.3 Kalman Filter Fundamentals

Time update Equations (Predict)

\[
\hat{X}_k^* = A \times \hat{X}_{k-1} + B \times U_k \\
P_k^* = A \times P_{k-1} \times A^T + Q
\]

(5)

(6)

Measurement Update Equations (Correction)

\[
K_k = P_k^* \times H^T \times (H \times P_k^* \times H^T + R)^{-1} \\
\hat{X}_k = \hat{X}_k^* + K_k \times (Z_k - H \times \hat{X}_k^*) \\
P_k = (I - K_k \times H) \times P_k^*
\]

(7)

(8)

(9)

\[P_k = E[(X_k - \hat{X}_k) \times (X_k - \hat{X}_k)^T] : \text{Covariance of State Error}\]

\(\hat{X}^* : \text{Estimated State Vector}\)

\(\hat{X}^* : \text{Predicted State Vector}\)
3.4 State Space Equations for Target Movement

State vector of the moving target

\[ X = \begin{bmatrix} x & y & v_x & v_y & a_x & a_y \end{bmatrix} \]

\[ \dot{a}_x = 0, \quad \dot{a}_y = 0 \]

Or

\[ \dot{a}_x = -(1/T) \times a_x \]
\[ \dot{a}_y = -(1/T) \times a_y \]

Equations of Movement

\[
\begin{align*}
x(k) &= x(k-1) + v_x(k-1) \times \Delta t + a_x(k-1) \times \Delta t^2 / 2 \\
y(k) &= y(k-1) + v_y(k-1) \times \Delta t + a_y(k-1) \times \Delta t^2 / 2 \\
v_x(k) &= v_x(k-1) + a_x(k-1) \times \Delta t \\
v_y(k) &= v_y(k-1) + a_y(k-1) \times \Delta t \\
a_x &= \left\{ 1 + \left( -1 / T \right) + \left( -1 / T \right)^2 / 2! \right\} \times a_x \\\na_y &= \left\{ 1 + \left( -1 / T \right) + \left( -1 / T \right)^2 / 2! \right\} \times a_y
\end{align*}
\]

3.5 State Space Equations for Target Movement

Matrices in the state space form

\[
A = \begin{bmatrix}
1 & 0 & 0 & 0.5 & 0 \\
0 & 1 & 0 & 1 & 0.5 \\
0 & 0 & 1 & 0 & 1 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & f
\end{bmatrix}
\]

\[ f = 1 + \left( -1 / T \right) + \left( -1 / T \right)^2 / 2! + \left( -1 / T \right)^3 / 3! + ... \]  

(10)

\[ B = [0] \quad \text{No control input} \]  

(11)

\[
X_k = \begin{bmatrix} x(k) & y(k) & v_x(k) & v_y(k) & a_x(k) & a_y(k) \end{bmatrix}
\]

(12)

\[
Z_k = \begin{bmatrix} x(k) & y(k) \end{bmatrix}
\]

(13)

\[
H = \begin{bmatrix}
1 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0
\end{bmatrix}
\]

(14)
3.6 State Space Equations for Target Movement

Designing Parameter for the Kalman Filter

\[ R = R_{val} \times \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \]  \hspace{1cm} (15)

\[ Q = Q_{val} \times \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \]  \hspace{1cm} (16)

\[ P_{c} = P_{val} \times \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \]  \hspace{1cm} (17)

\[ T : \text{Scalar value} \]  \hspace{1cm} (18)

3.7 Determine designing parameters

Fig. Real and Noise Tracks of Model Ship in Simulation
3.8 Determine designing parameters

Performance Indices

Position Error Reduction (PER)
Maximum Position Error (MPE)
Speed Error Reduction (SER)
Maximum Speed Error (MSE)

\[
\text{PER} = \frac{\sum \Delta d_j(i)}{\sum \Delta d_j^2(i)} \quad \Delta d_j, \Delta d_j \text{ absolute position error and position error after filtering}
\]

\[
\text{SER} = \frac{\sum \Delta V_j^2(i)}{\sum \Delta V_j^2(i)} \quad \Delta V_j, \Delta V_j \text{ absolute speed error and speed error after filtering}
\]

\[MPE = \max \{\Delta d_j(i)\}\]

\[MSE = \max \{\Delta V_j(i)\}\]

\[i = 1: N \text{ (number of sampling data)}\]

3.9 Determine designing parameters

Fig. Performance Indices as Function of P_val and Q_val in Turning Maneuver
3.10 Determine designing parameters

![Graph showing performance indices as function of R_val]

- $P_{val} = 1000$
- $Q_{val} = 0.3$
- $T = 3$
- $R_{val} = 2.0$
- $\text{PER} = 0.72$
- $\text{SER} = 0.16$
- $\text{MPE} = 2.1$
- $\text{MSE} = 1.3$

3.11 Determine designing parameters

![Graph showing track of model ship before and after filtering]

- [Graph showing model ship speed and course before and after filtering]

![Graph showing model ship speed and course before and after filtering]
3.12 Filtering Result

Fig. Speed, Course and Track of a Radar Target Before and After Filtering

3.13 Filtering Result

Fig. Speed, Course and Track of a Radar Target Before and After Filtering
4.1 Distribution of target ship

4.2 Estimated area

- Nakanose traffic route
- Uraga suido traffic route
- East faiyway
- West of Nakanose
4.3 Uraga suido traffic route (Heading)

4.4 Uraga suido traffic route (Starbord, Port)
4.5 Nakanose traffic route

4.6 East fairway
4.7 West of Nakanose

4.8 Distribution of Heading