DAPsを用いた高精度追尾技術に関する研究

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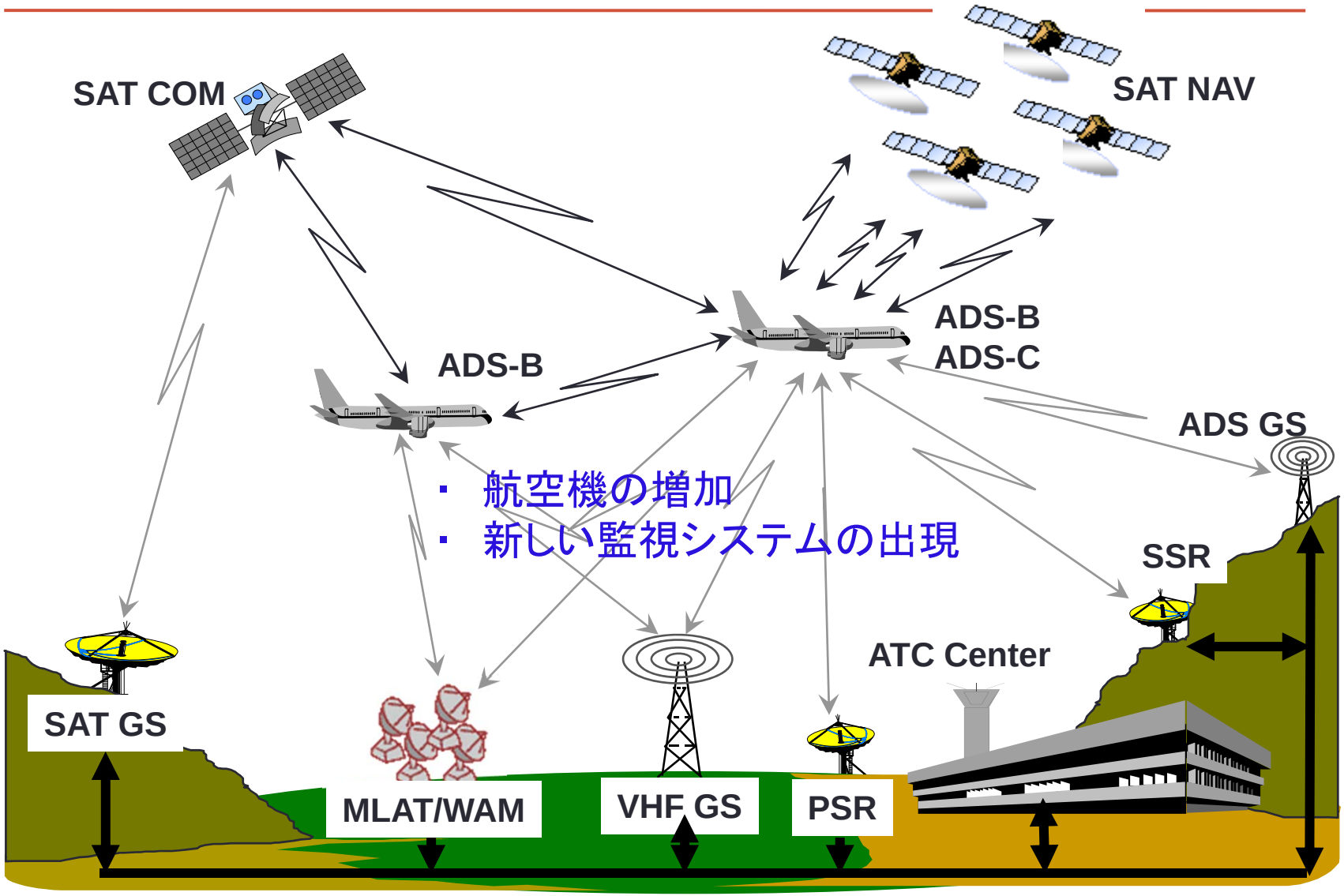
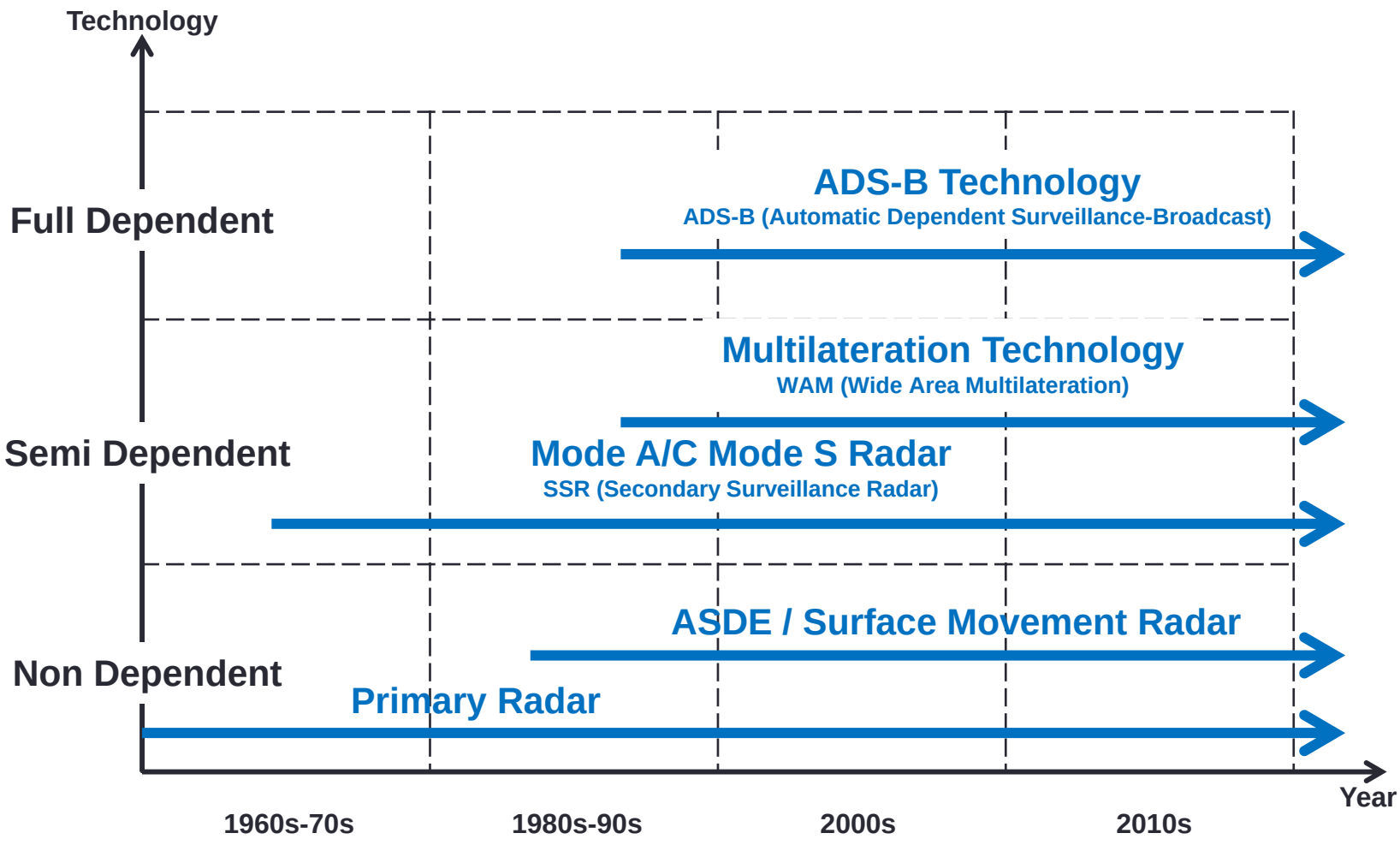
背景


SAT COM
SAT NAV
ADS-B
ADS-B
ADS-C
ADS GS
・ 航空機の増加
・ 新しい監視システムの出現
SSR
ATC Center
SAT GS
MLAT/WAM
VHF GS
PSR

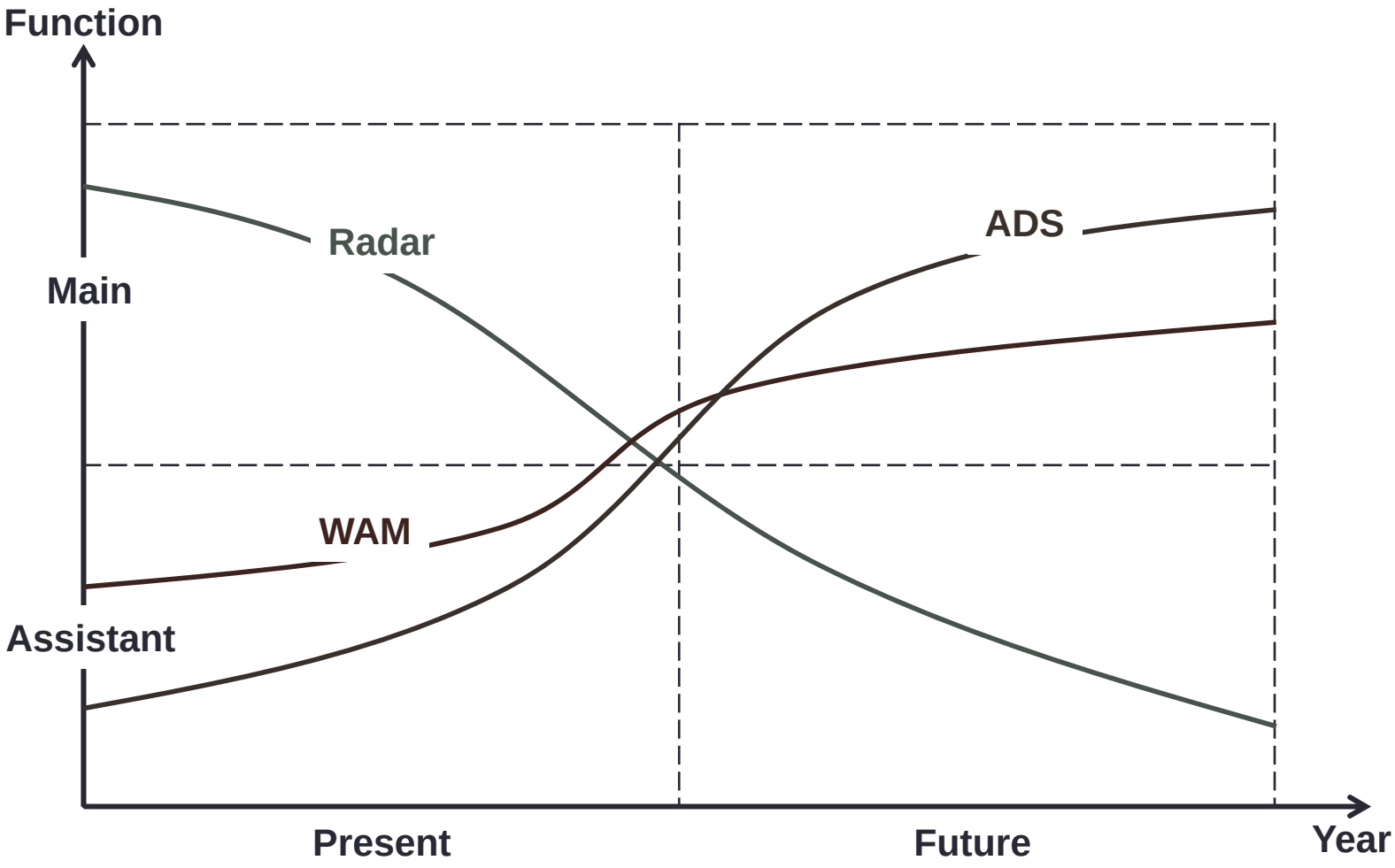
背景


Technology
Full Dependent
Semi Dependent
Non Dependent
ADS-B Technology
ADS-B (Automatic Dependent Surveillance-Broadcast)
Multilateration Technology
WAM (Wide Area Multilateration)
Mode A/C Mode S Radar
SSR (Secondary Surveillance Radar)
ASDE / Surface Movement Radar
Primary Radar
Year
1960s-70s
1980s-90s
2000s
2010s

監視技術の比較

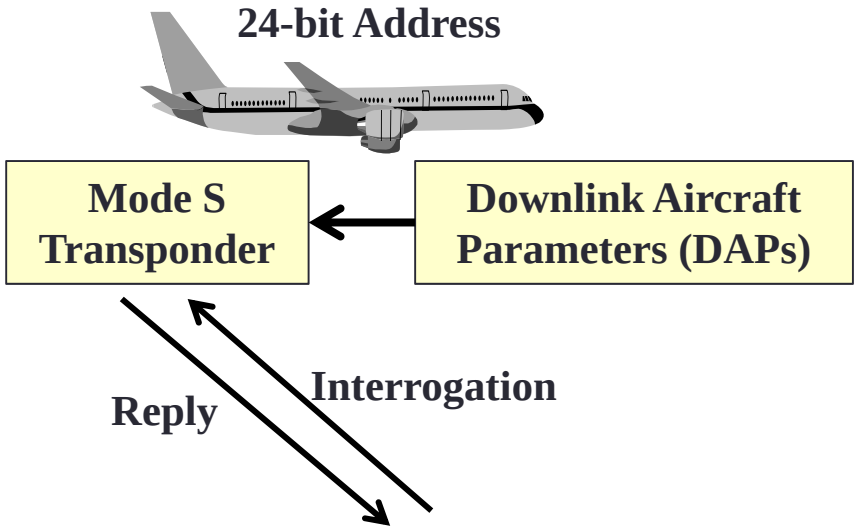
	Integrity	Update Rate	Accuracy	Data Link
SSR Mode S	○ Range: 250NM Probability of detection: >97%	△ Antenna rotation time: 4s~12s	△ Range: 30m Azimuth: <0.06deg	○ Downlink Aircraft Parameters (DAPs)
Multi lateration	△ Based on the location of ground stations	○ Refresh period: <= 1s	○ Based on the location of ground stations	△ Limited to use
ADS-B	△ Range: 250NM Not all aircrafts are equipped	○ Refresh period: <= 1s	○ Position: 10m Altitude: 25fts	△ Limited to use

監視技術の動向

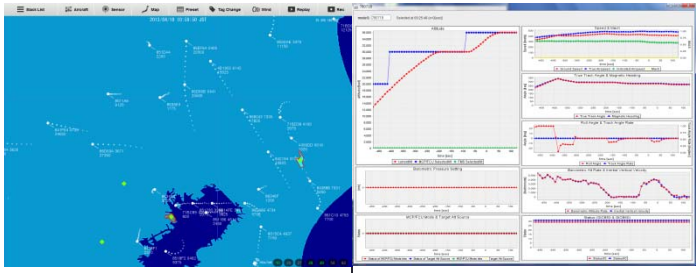


Mode S Radar

- **Surveillance modes**
  - **Elementary Surveillance**
    - **24-bit address**
    - **Position**
    - **Altitude, …**
  - **Enhanced Surveillance**
    - **Ground Speed**
    - **True Track Angle**
    - **Track Angle Rate, …**



Monitor



Controller

Mode S Radar

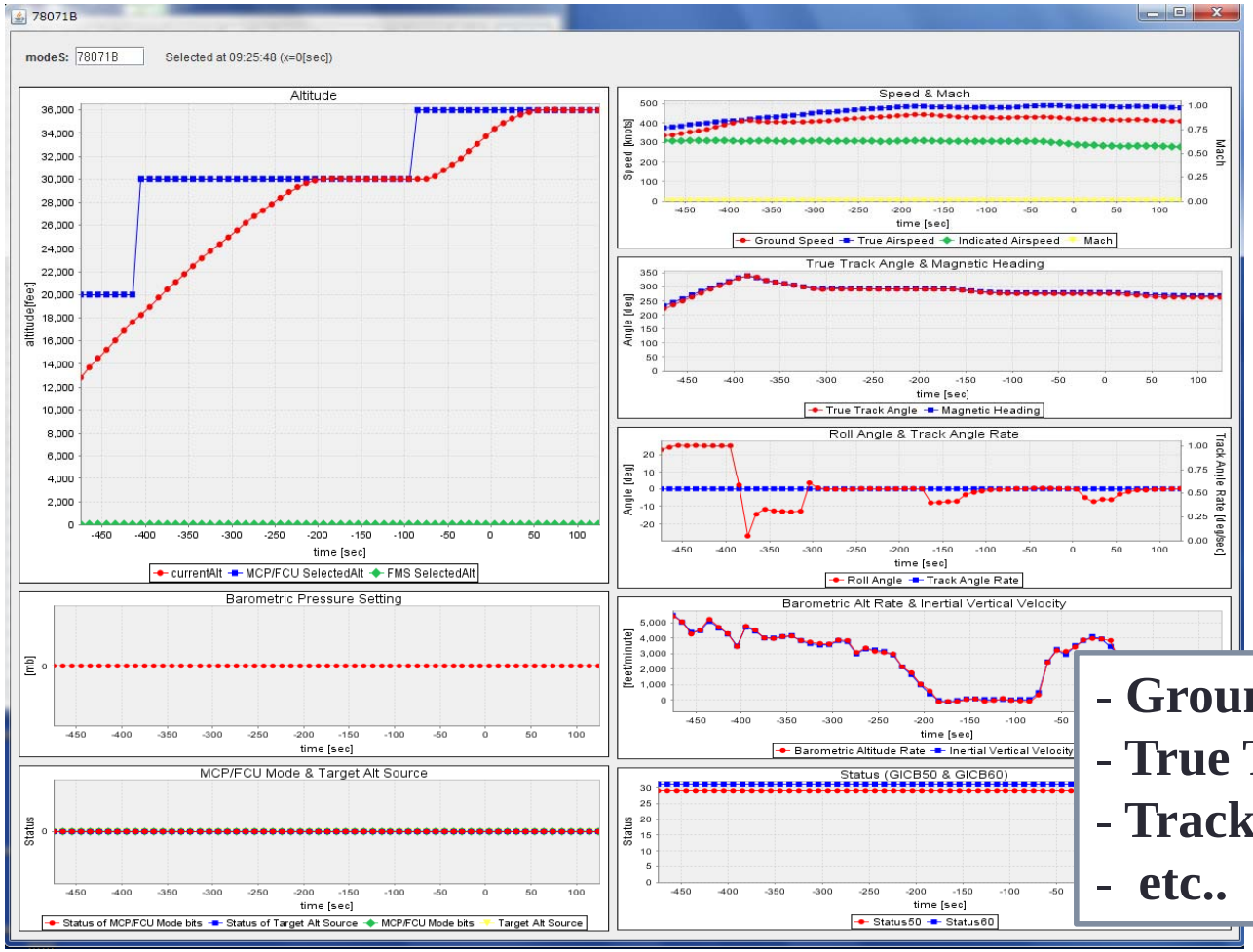
Mode S Radar

- **Elementary Surveillance**

- 24-bit address
- Accurate Position
- 25ft resolution Altitude

Mode S Radar

- **Enhanced Surveillance**



- **Ground Speed**
- **True Track Angle**
- **Track Angle Rate**
- **etc..**

Mode S Radar

- **Experiment System in ENRI**

- Update rate 10 seconds
- Coverage radius 250NM (450km)

SSR in Chofu

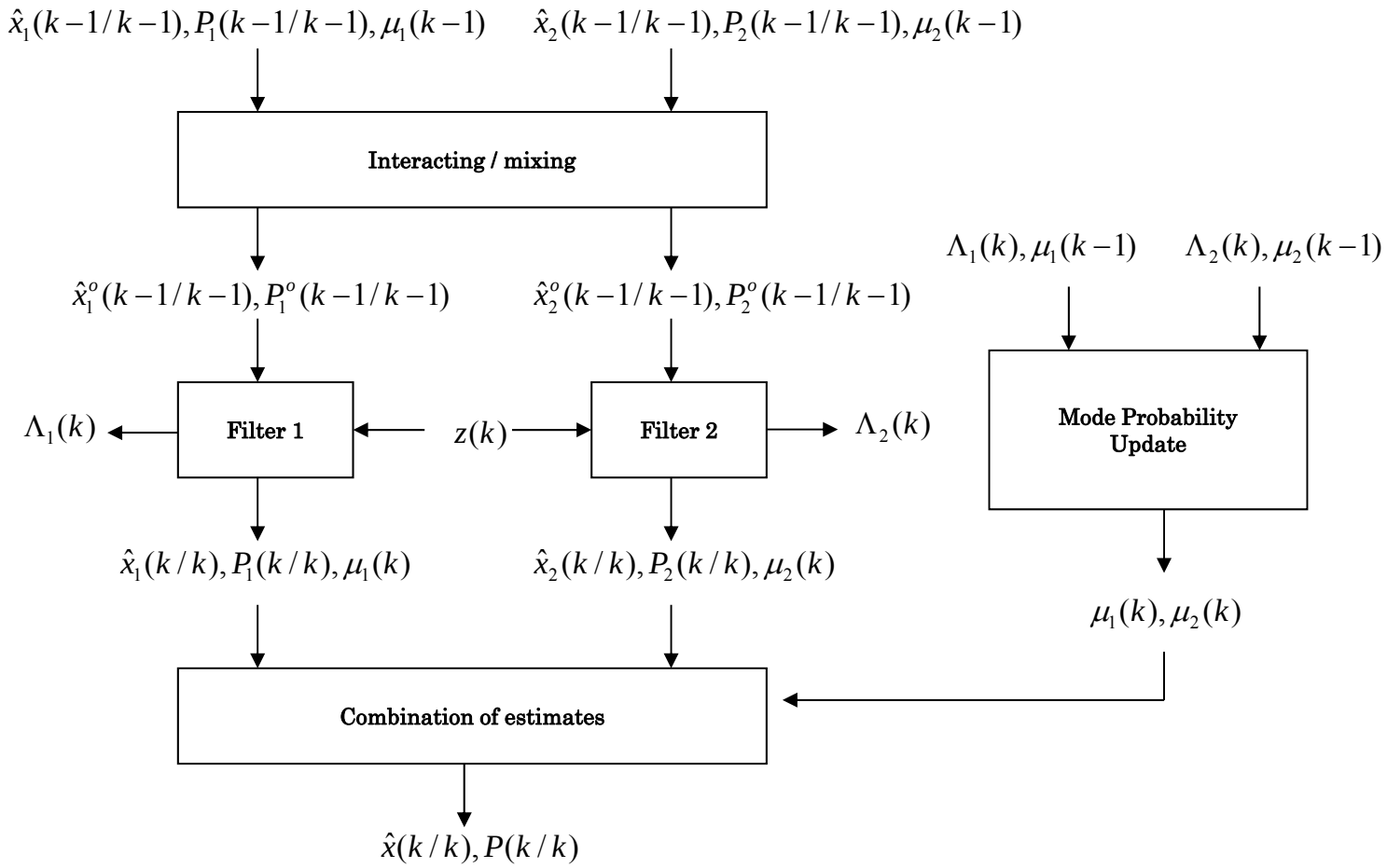
- Update rate 4 seconds
- Coverage radius 200NM (370km)

SSR in Iwanuma

- DAPs Capability
- Network Coordination Capability

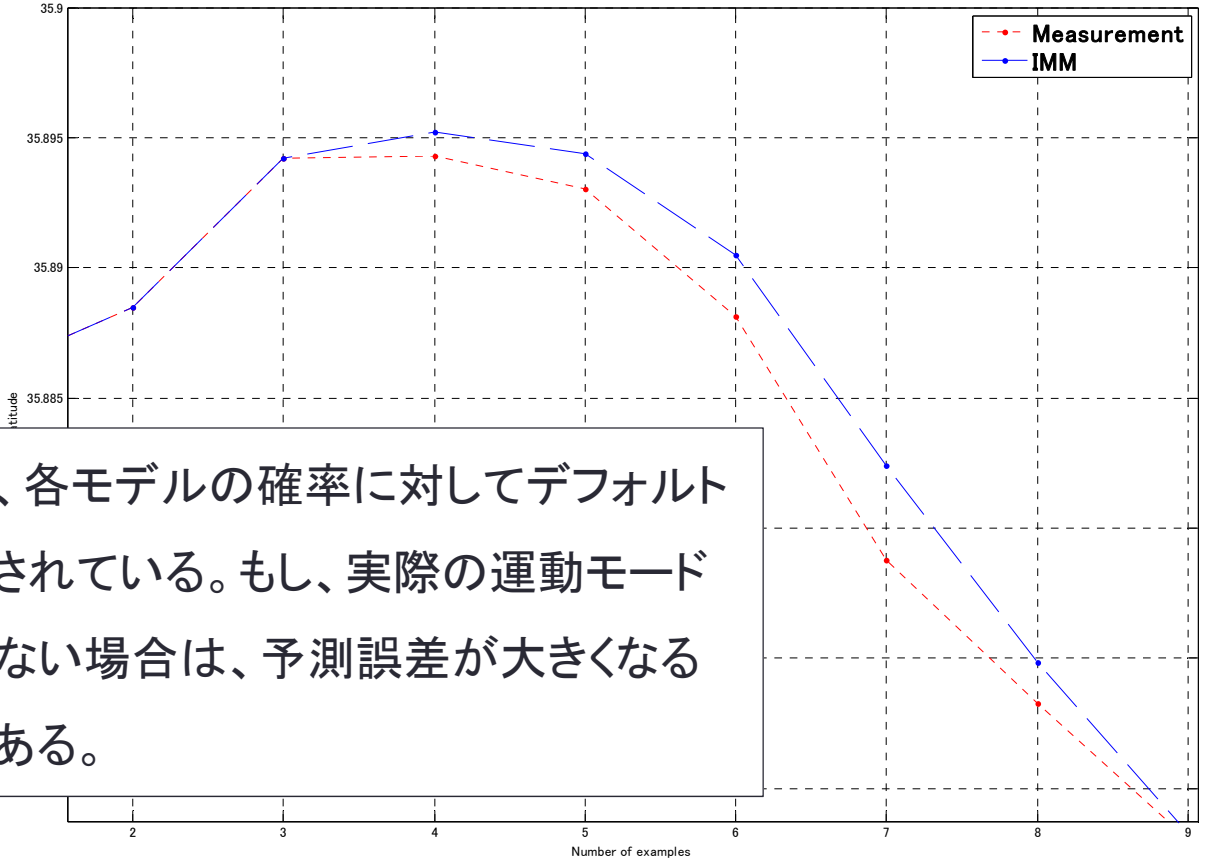
高精度追尾システム

- **IMM (Interacting Multiple Model)**



高精度追尾システム

- **IMM Filterの問題**

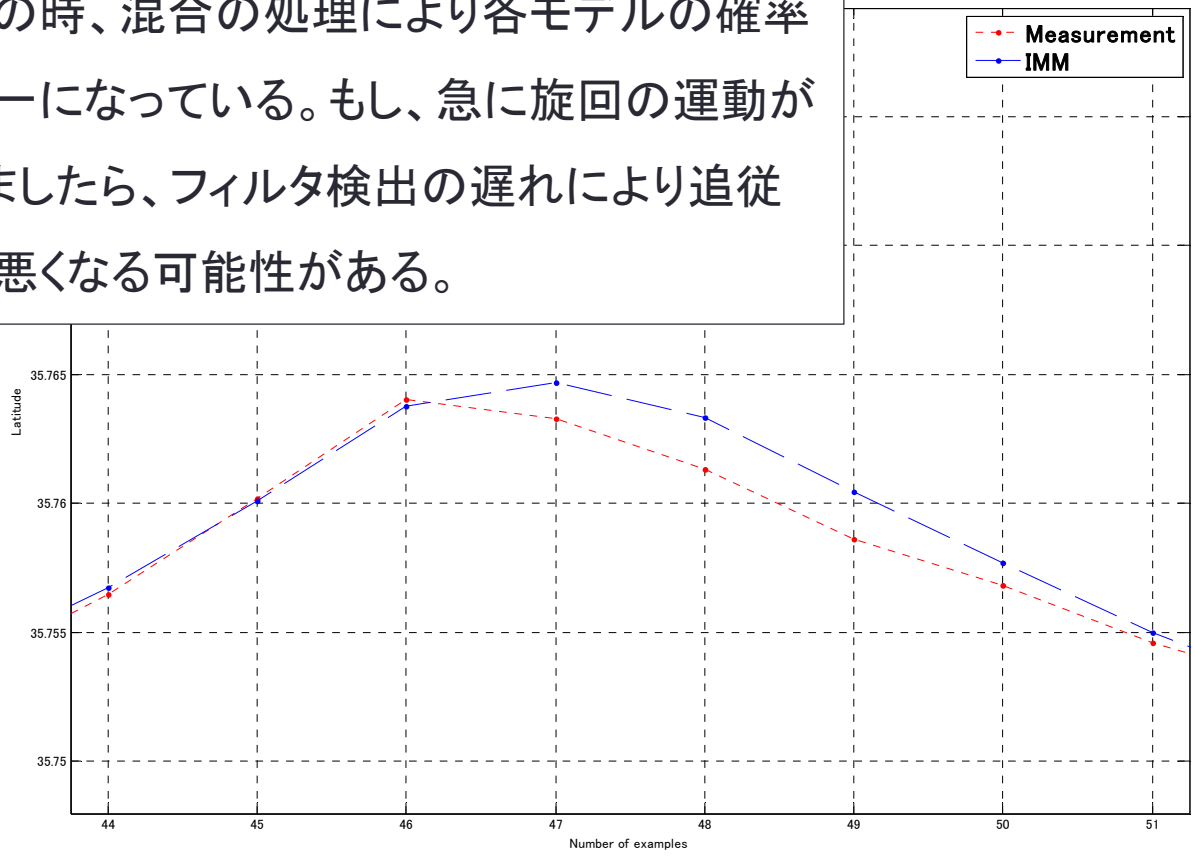


- 初期の時、各モデルの確率に対してデフォルト値が設定されている。もし、実際の運動モードとマッチしない場合は、予測誤差が大きくなる可能性がある。

高精度追尾システム

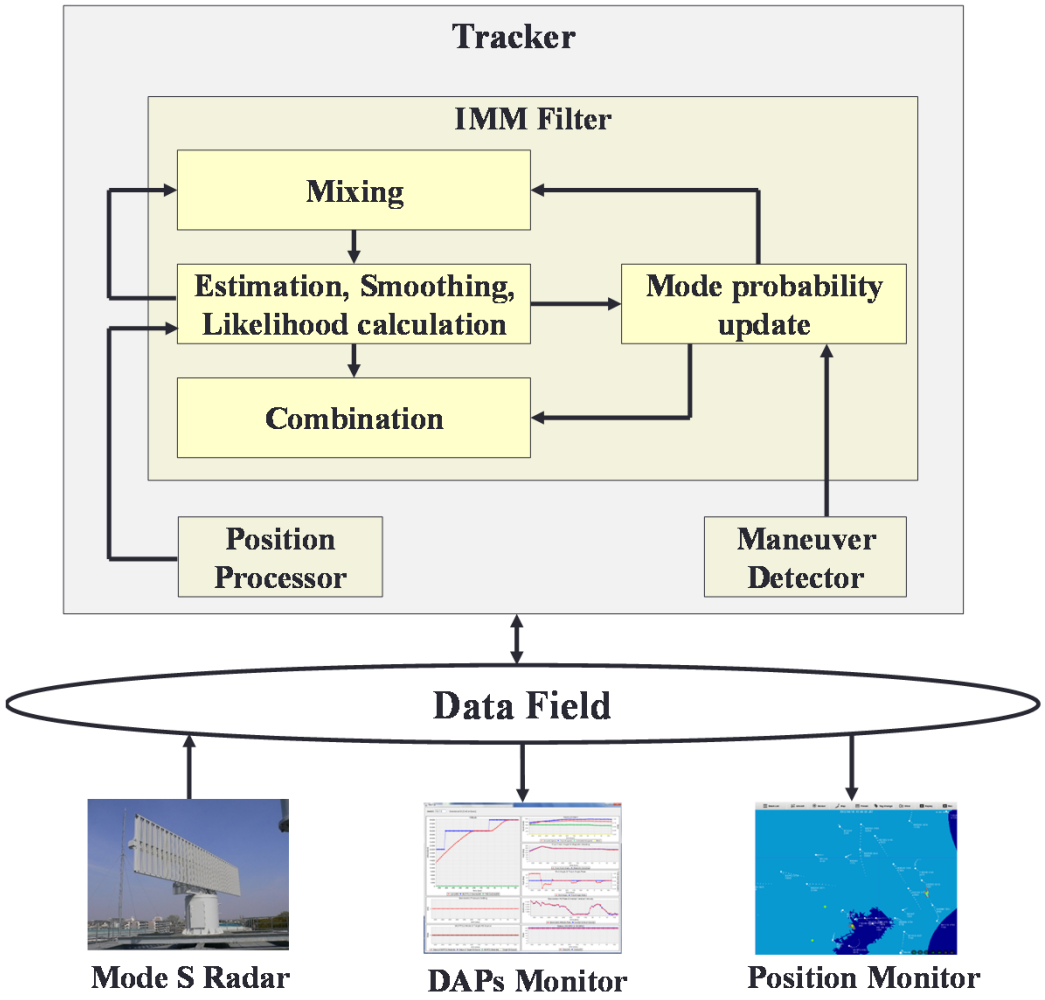
- **IMM Filterの問題**

  - 後期の時、混合の処理により各モデルの確率が均一になっている。もし、急に旋回の運動がありましたら、フィルタ検出の遅れにより追従性が悪くなる可能性がある。



高精度追尾システム

- **System Architecture**



高精度追尾システム

- **Detection parameters**

$C_v = V_{gs}(k) - V_{gs}(k-1)$　　等速直線モデル、加速度直線モデル

$C_a = R(k-1) \cdot W(k-1)$　　旋回モデル

- **Initial tracking period**

if $(C_a \neq 0)$, then

$\mu_1(k) = \min\{\mu_1(k-1), \mu_2(k-1), \mu_3(k-1)\}$

$\mu_2(k) = \mathrm{mid}\{\mu_1(k-1), \mu_2(k-1), \mu_3(k-1)\}$

$\mu_3(k) = \max\{\mu_1(k-1), \mu_2(k-1), \mu_3(k-1)\}$

if $(C_a = 0 \,\&\, C_v \neq 0)$, then

$\mu_1(k) = \mathrm{mid}\{\mu_1(k-1), \mu_2(k-1), \mu_3(k-1)\}$

$\mu_2(k) = \max\{\mu_1(k-1), \mu_2(k-1), \mu_3(k-1)\}$

$\mu_3(k) = \min\{\mu_1(k-1), \mu_2(k-1), \mu_3(k-1)\}$

高精度追尾システム

- **Later tracking period**

if $(C_a \neq 0 \,\&\, \mu_3(k-1) < 0.5)$, then

$\mu_1(k) = \min\{e_1(k-1), e_2(k-1), e_3(k-1)\} - 0.2$

$\mu_2(k) = \mathrm{mid}\{e_1(k-1), e_2(k-1), e_3(k-1)\} - 0.1$

$\mu_3(k) = \max\{e_1(k-1), e_2(k-1), e_3(k-1)\} + 0.3$

if $(C_a = 0 \,\&\, C_v \neq 0 \,\&\, \mu_2(k-1) < 0.5)$, then

$\mu_1(k) = \mathrm{mid}\{e_1(k-1), e_2(k-1), e_3(k-1)\} - 0.1$

$\mu_2(k) = \max\{e_1(k-1), e_2(k-1), e_3(k-1)\} + 0.3$

$\mu_3(k) = \min\{e_1(k-1), e_2(k-1), e_3(k-1)\} - 0.2$

- Prediction error rate

$$e_i(k-1) = \frac{\varepsilon_i(k-1)}{\sum_{i=1} \varepsilon_i(k-1)}$$

$$\varepsilon_i(k-1) = |x_m(k) - x_p(k-1)| + |y_m(k) - y_p(k-1)|$$

評価実験

- **Comparison**
  - **Parameters**

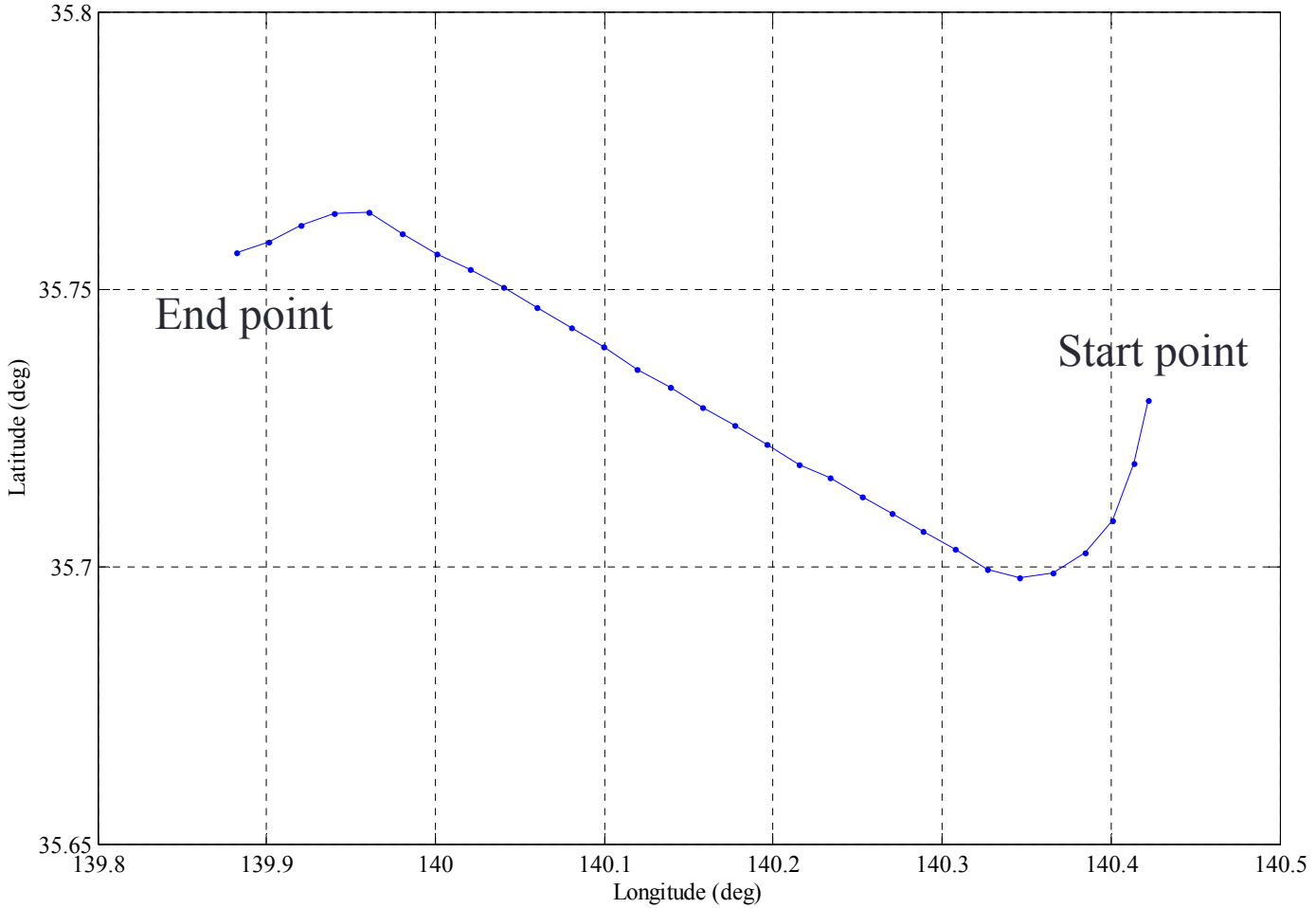
Model	Process noise	Measurement noise
Constant velocity	0.01g	60m
Constant acceleration	g	
Coordinated Turn	0.1g	

  - **Model transition probabilities**

$$P = \begin{bmatrix} 0.95 & 0.025 & 0.025 \\ 0.025 & 0.95 & 0.025 \\ 0.025 & 0.025 & 0.95 \end{bmatrix}$$

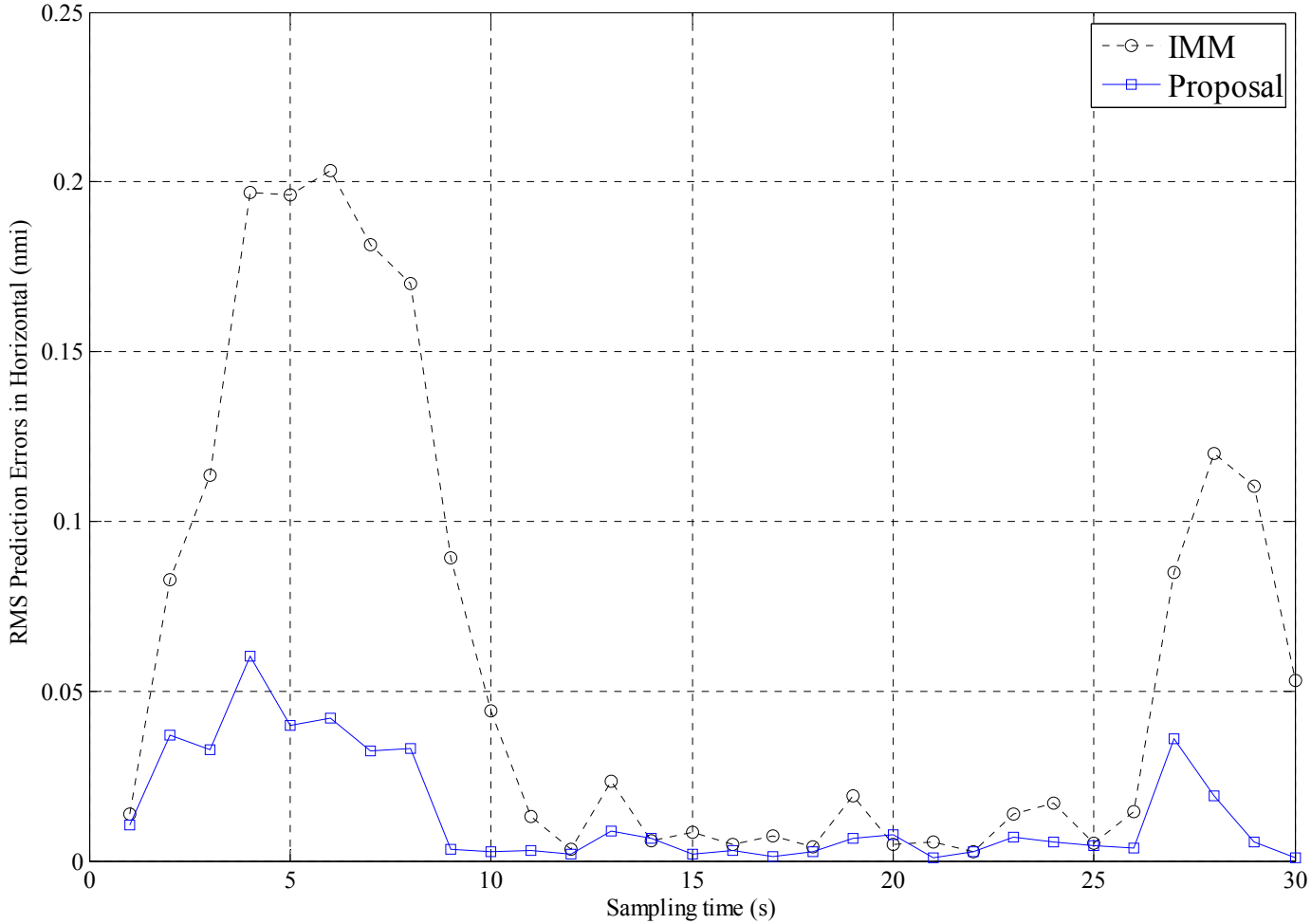
評価実験

- **Trajectory**



評価実験

- **Computer simulations: RMS Position errors**



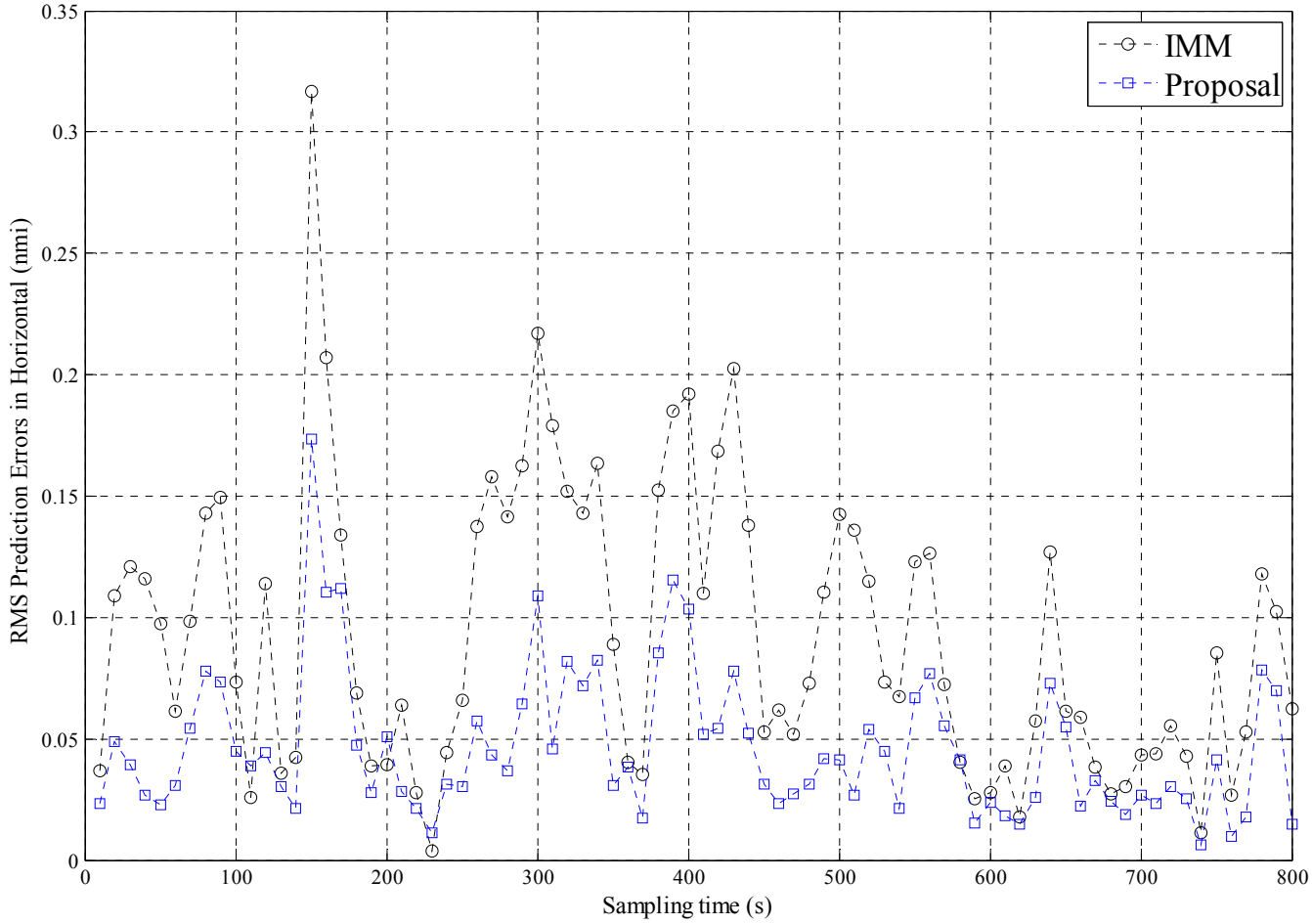
評価実験

- **Practical experiments: RMS Prediction errors**

Sampling time (sec)	Measurement points	RMS error (nmi)		%Reduction
		Proposal	IMM	
[0, 100)	62	0.0442	0.1006	56.06
[100, 200)	51	0.0657	0.1022	35.69
[200, 300)	49	0.0433	0.1022	57.63
[300, 400)	37	0.0673	0.1331	49.41
[400, 500)	44	0.0432	0.1111	61.09
[500, 600)	48	0.0427	0.0807	47.16
[600, 700)	64	0.0311	0.05	37.73
[700, 800)	57	0.0317	0.0601	47.33

評価実験

- **Practical experiments: RMS Prediction errors**



まとめ

1. 背景
   航空機の増加、新しい監視技術の出現、
   DAPsデータの高精度化

2. 課題
   - Mode Sレーダ監視精度の向上
   - 高信頼な追尾システムの構築

3. 実験システムの上で、DAPsを用いた高精度追尾技術を提案した