GNSS/INS Integration based on Machine Learning Approaches
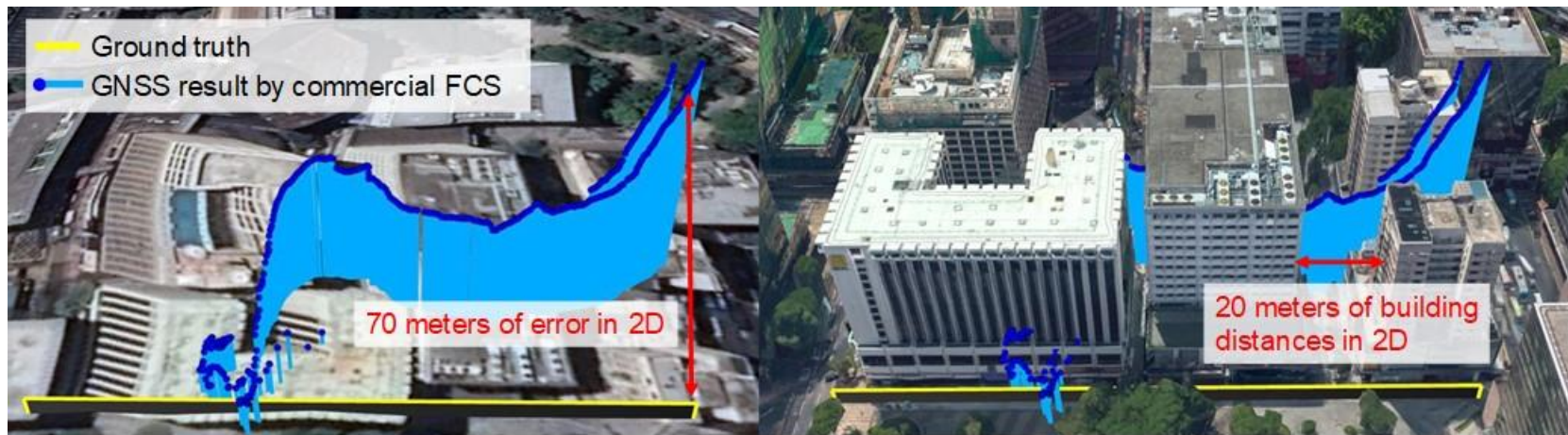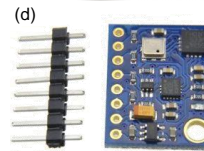
- Identify the GNSS accuracy by model trained by machine learning approaches.

- Revise the R matrix in the Kalman filter integration.

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GNSS/INS Integration based on Machine Learning Approaches

GPS Parameters outputted Pixhawk 2	Description
GPSTime	Time data with GPS week/second format
EPH	Standard deviation of horizontal positioning error
EPV	Standard deviation of vertical positioning error
nSat	Number of satellites for positioning
N	GPS noise
J	GPS jamming
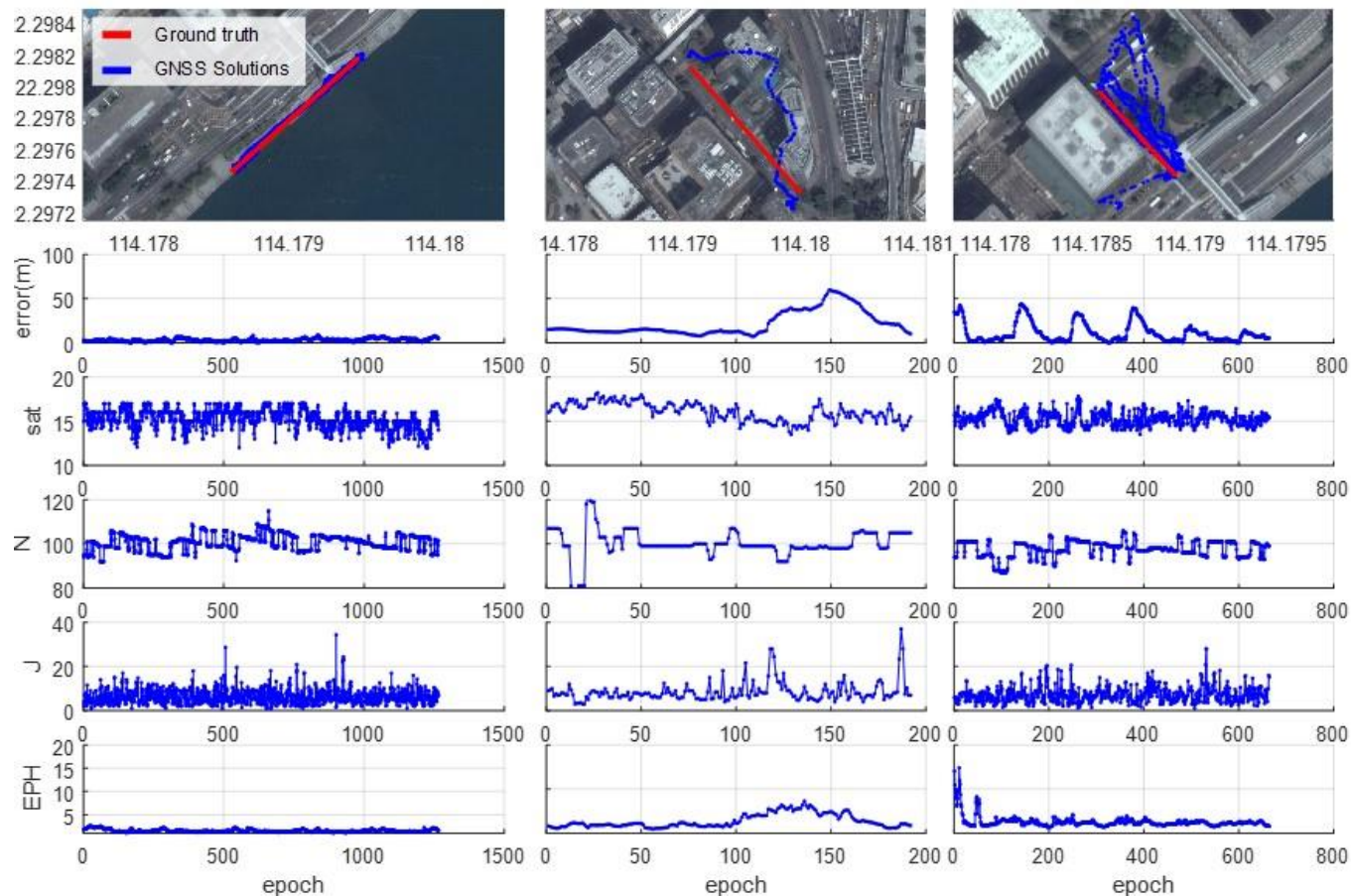
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Adaptive Kalman filter architecture

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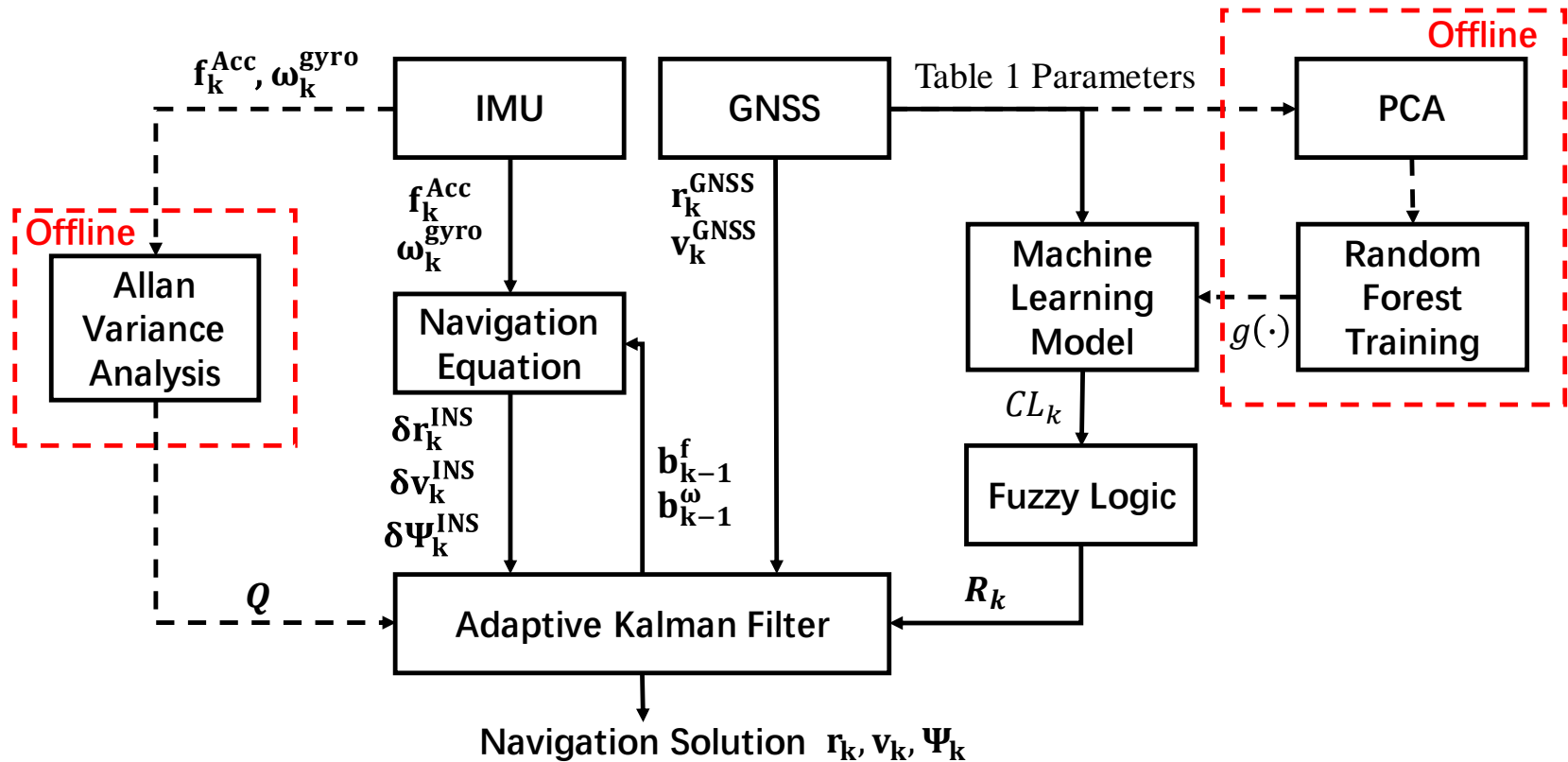
Principle Component Analysis (PCA)

- GNSS features weighting analysis and dimensionality reduction

- Classification range

	PCA-1	PCA-2	PCA-3
EPH	0.023	0.214	0.242
EPV	0.067	0.488	0.718
VelN	0.001	0	0.029
VelE	0.003	0.011	0.021
VelD	0.004	0.012	0.053
nSat	0.038	0.331	0.208
N	0.184	0.754	0.613
J	0.976	0.193	0.051
Eigenvalue	399.0671	35.9236	9.9084

EPH:

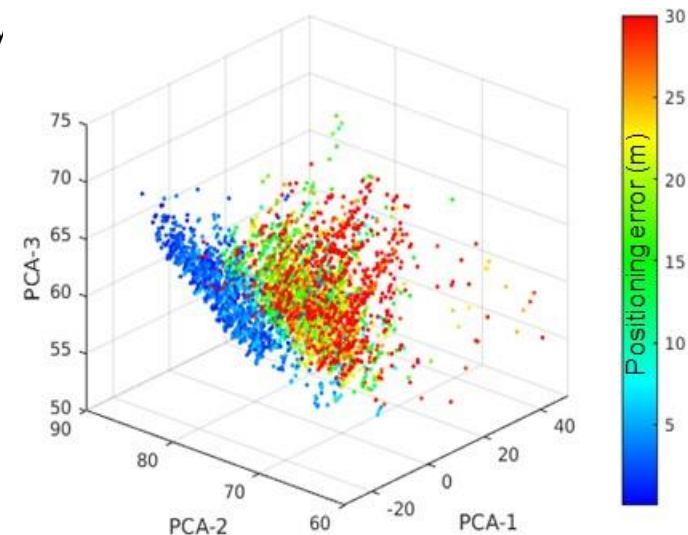standard deviation of horizontal positioning error

EPV:

standard deviation of vertical positioning error

nSat:

number of satellites for positioning
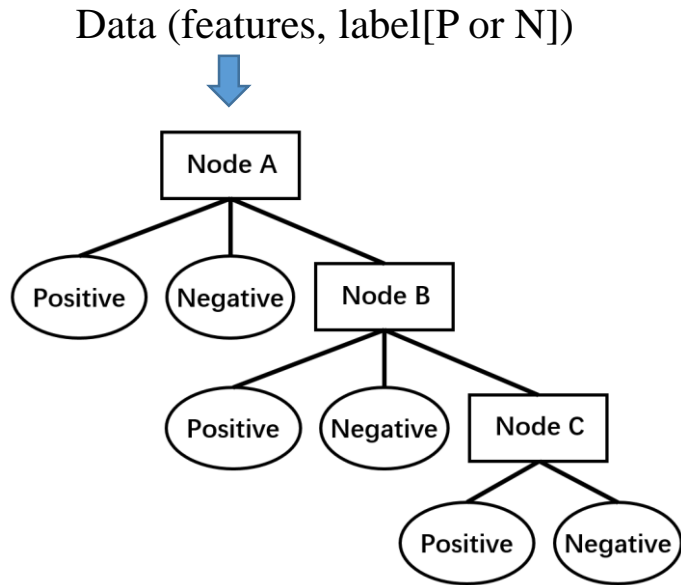
N: GNSS noise

J: GNSS jamming

Class	Error (m)	Label
Health (HL)	< 5	1
Slightly shift (SS)	5 – 13	2
Inaccurate (IA)	13 – 23	3
Danger (DG)	> 23	4

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Supervised Machine Learning

Decision Tree:

Data (features, label[P or N])

Separate data base on different features until perfect separation

Random Forest:

- Subset of data and features building each tree
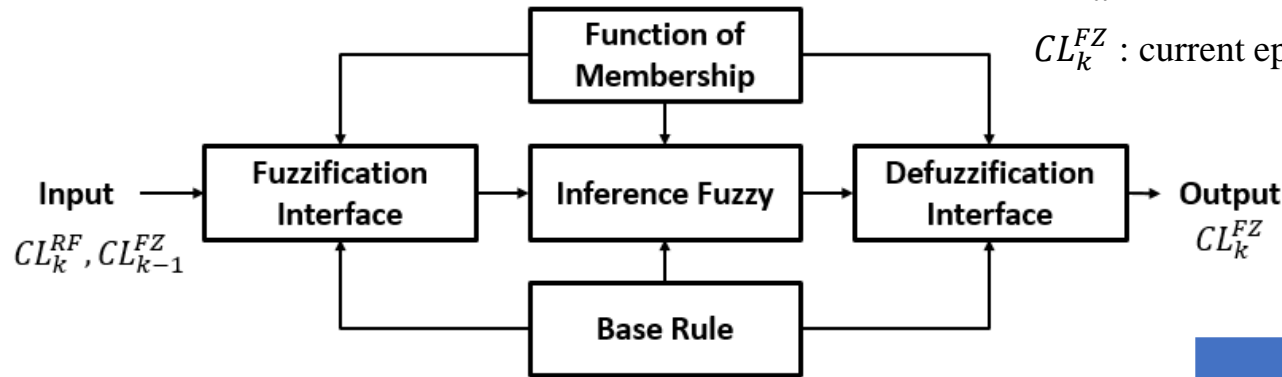
- Average multiple trees for classification

$$g^{RT}(\text{X}) = \frac{1}{B}\sum_{b=1}^{B} g_b^{DT}(\text{X}_b)$$

Improvement:
1. Corrects the overfitting problem
2. Cancel out the variance from training sets

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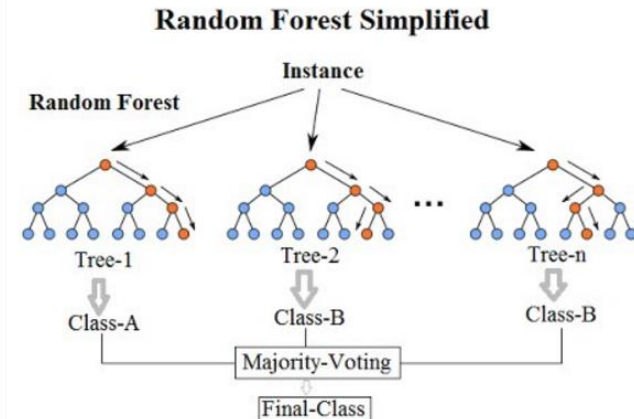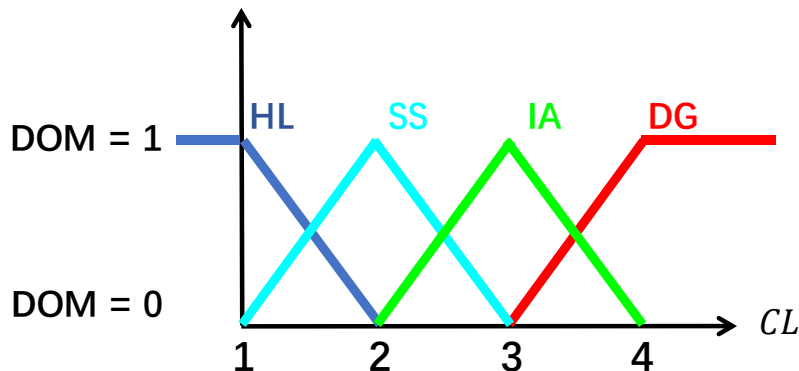
Fuzzy Logic

CL_{k-1}^{FZ} : last epoch GNSS condition estimation from fuzzy logic

CL_{ml}^{RF} : current epoch GNSS condition from RF

CL_k^{FZ} : current epoch GNSS condition estimation

Membership function

	CL_{ml}^{RF}			
	HL (1)	SS (2)	IA (3)	DG (4)
HL (1)	HL (1)	HL (1)	SS (2)	SS (2)
SS (2)	HL (1)	SS (2)	SS (2)	IA (3)
IA (3)	SS (2)	IA (3)	IA (3)	DG (4)
DG (4)	IA (3)	IA (3)	DG (4)	DG (4)

CL_{k-1}^{FZ}

Base rules

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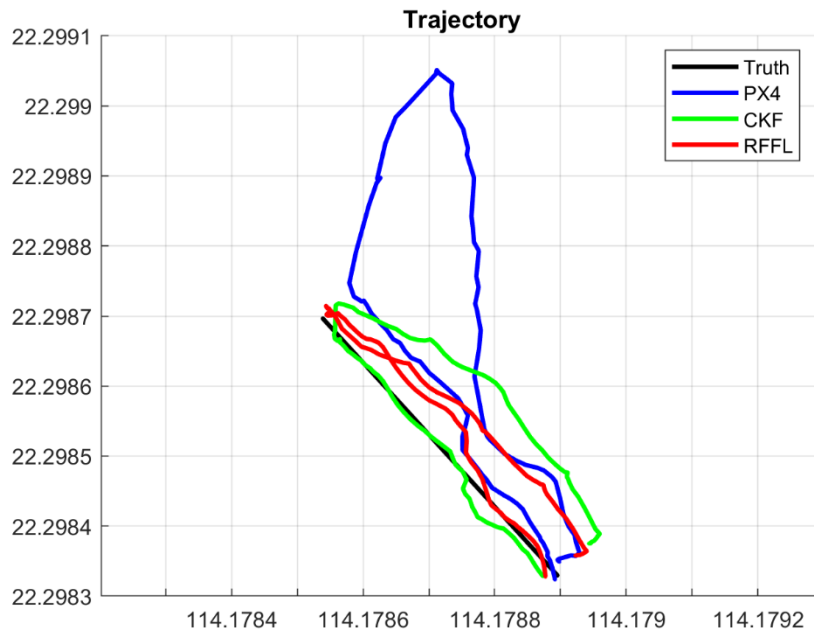
GNSS/INS Integration Result
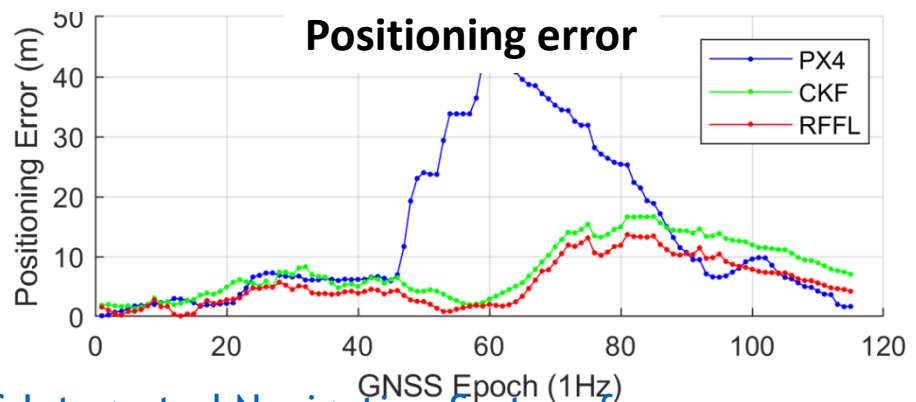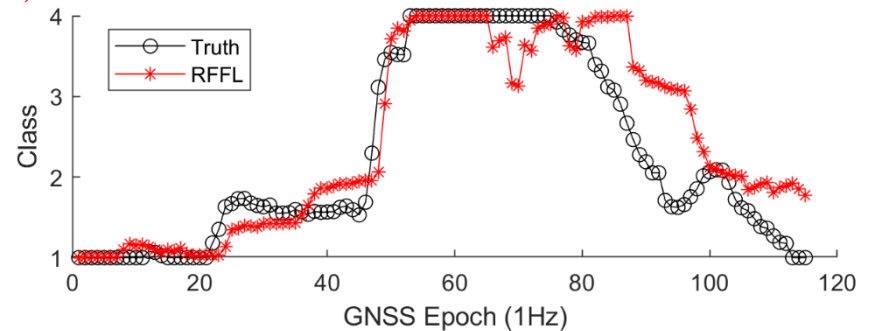
Truth: Ground truth

PX4: original positioning algorithm (commercial)

CKF: fixed measurement noise covariance (conventional)

RFFL: random forest with fuzzy logic (proposed)

**Accuracy Class
(4: unreliable, 1 accurate)**

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