Onboard Train Localization Assisted by Surrounding Structure Identification Using One-dimensional LiDAR Sensor

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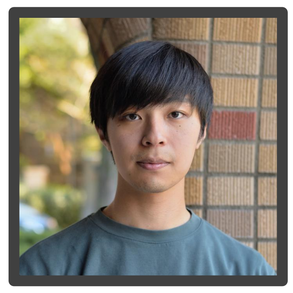

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1. Introduction

- Train localization: important for safety of railway systems
- Too much ground equipment in conventional methods

http://tx1000dc1500.blog.fc2.com/blog-entry-17.html

Strong demand for onboard train localizing system!

2. Related work

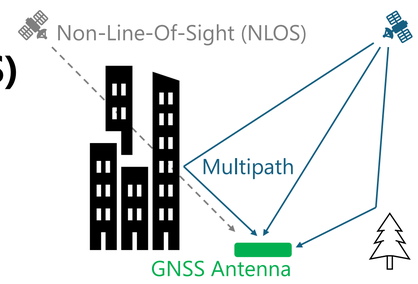
Problem of relative positioning

- Drift error, bias error, temperature dependence → accumulated error

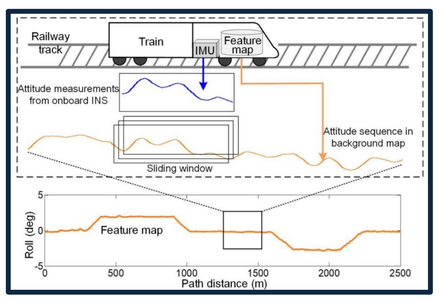
Demand for absolute positioning

Global Navigation Satellite System (GNSS)

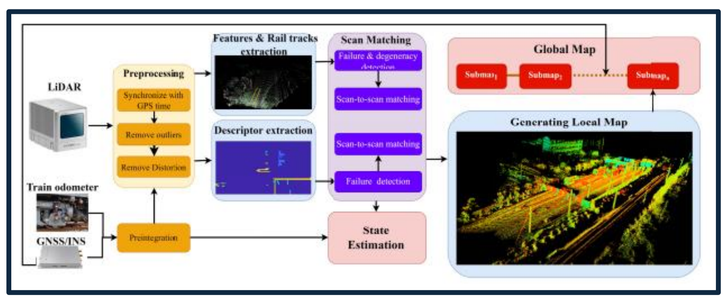
- Difficult to predict positioning error
  - Non-Line-Of-Sight (NLOS)
  - Multipath



Detecting surrounding features



Y. Zhou, et al., *IEEE Transactions on Instrumentation and Measurement*, 71, 1-13, 2022.



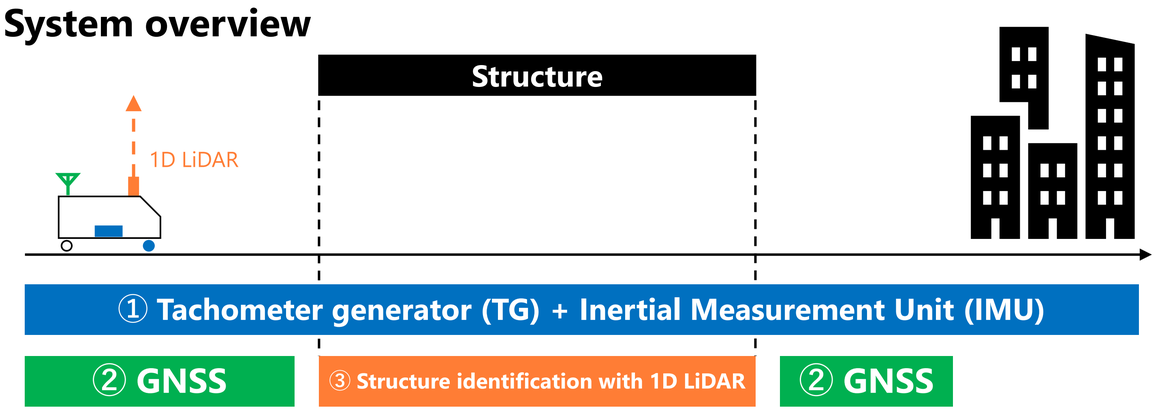
Y. Wang, et al., *IEEE Sensors Journal*, 22(14), 14501-14512, 2022.

Requirements

- Seeking unchanging features
- Avoiding expensive sensors (3D LiDAR, laser doppler velocimeter)
- Using high-sampling-rate sensors for high-speed railways

3. Methodology

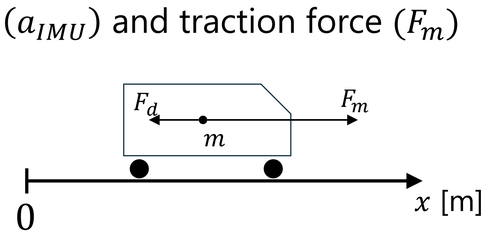
System overview



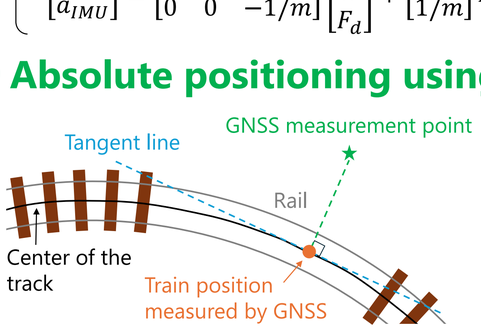
① Continuous and relative positioning using TG and IMU

- Kalman filter using TG (x_{TG}), IMU (a_{IMU}) and traction force (F_m)

$$\begin{cases} \dot{x} = \begin{bmatrix} \dot{x} \\ \ddot{x} \\ \dot{F}_d \end{bmatrix} = \underbrace{\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & -1/m \\ 0 & 0 & 0 \end{bmatrix}}_{A} \begin{bmatrix} x \\ \dot{x} \\ F_d \end{bmatrix} + \underbrace{\begin{bmatrix} 0 \\ 1/m \\ 0 \end{bmatrix}}_{B} F_m \\ z = \begin{bmatrix} x_{TG} \\ a_{IMU} \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1/m \end{bmatrix}}_{C} \begin{bmatrix} x \\ \dot{x} \\ F_d \end{bmatrix} + \underbrace{\begin{bmatrix} 0 \\ 1/m \end{bmatrix}}_{D} F_m \end{cases}$$



② Absolute positioning using GNSS in open-sky area



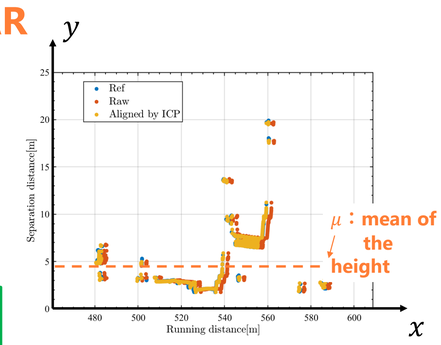
- Pre-defined GNSS-available section
- Tangent line is approximately created by track map

③ Structure identification with 1D LiDAR

Creating point cloud data using estimated position x and 1D LiDAR measurement

Matching to reference point cloud

Testing the result of matching



Parameter	Threshold
RMSE	$RMSE_{th} = 0.5\sim2$ [m]
Moving in y-axis	$Y_{MOVEth} = 0.2\mu$ [m]
Rotation	$ROT_{th} = 10\sim20$ [deg]

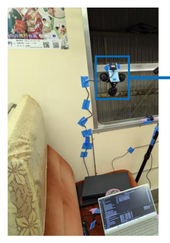
→

Matching OK & Test OK	Desired
Test NG	No location info but safe
Matching NG & Test OK	*Wrong location, dangerous*

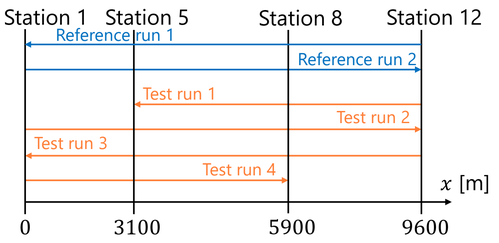
4. Experimental validation

Experimental setup in the railway environment

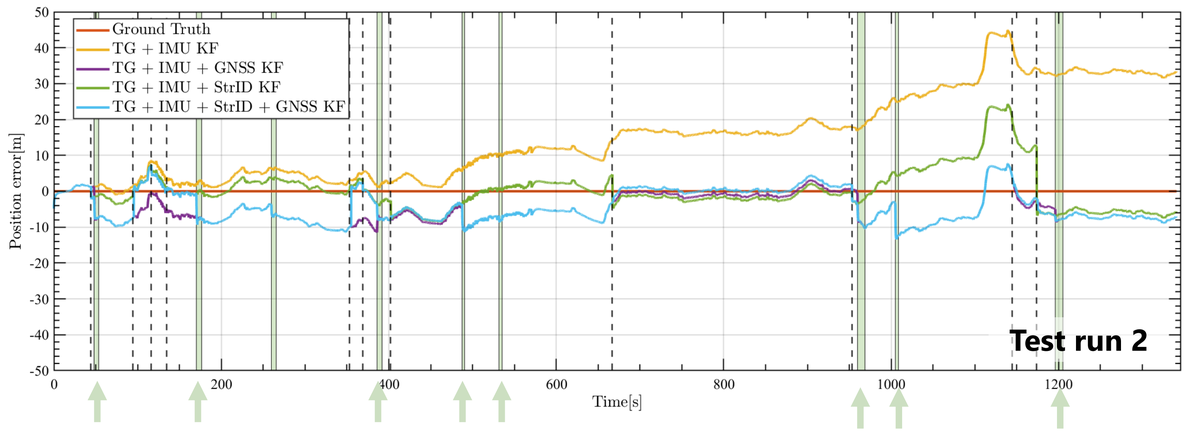
Test train vehicle



1D LiDAR placement



Experimental result: Errors of estimated train position

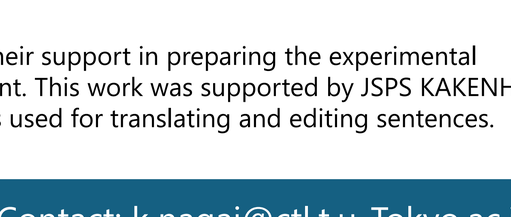


Pre-defined GNSS available area (nearly open-sky environment)

No.	Method	RMS [m]	Max. error(abs) [m]
1	TG+IMU	6.59	16.3
1	TG+IMU+GNSS	6.86	14.5
1	TG+IMU+StrID	2.87	7.65
1	TG+IMU+StrID+GNSS	5.60	14.5
2	TG+IMU	19.3	45.0
2	TG+IMU+GNSS	6.43	13.4
2	TG+IMU+StrID	5.64	24.3
2	TG+IMU+StrID+GNSS	6.15	13.4
3	TG+IMU	8.06	21.2
3	TG+IMU+GNSS	6.71	15.7
3	TG+IMU+StrID	2.67	6.75
3	TG+IMU+StrID+GNSS	6.09	15.7
4	TG+IMU	3.86	8.18
4	TG+IMU+GNSS	5.55	11.2
4	TG+IMU+StrID	3.45	8.52
4	TG+IMU+StrID+GNSS	5.45	11.2

*The ground truth is created using a non-causal offline process using GNSS, IMU, TG, and Trackmap. This means that the ground truth cannot be obtained in real time.
*"No." indicates the number of test runs.
*"StrID" is the abbreviation of "Structure IDentification."

- Only using TG & IMU is insufficient due to accumulated error
- Structure identification using 1D LiDAR enhances localization accuracy
- GNSS is suffer from measurement delay in time domain
  - Calculation time, filtering in receiver (black box)



Identification failure (eliminated by the test)

5. Conclusion & future work

- Proposal of onboard localization method only using inexpensive sensors
- Higher position accuracy of proposed structure identification
  - Several meters of RMSE, ~70% suppressing maximum error

Future work

GNSS time delay compensation, Improving environmental robustness

Acknowledgement

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