VE&VM 450 Design Review 3

Sensor Fusion System for Automated Guided Vehicle

Sponsor: Prof. Mian Li

Team 6: Xia Binyu

Wang Jiaqi

Qian Xinyu

Wu Jiahao

Ge Jintian

Introduction

AGV-Localization ——Where am I?

Problem:

- Different sensor features and shortcomings
- Trade off among frequency, accuracy and cost

Solution:

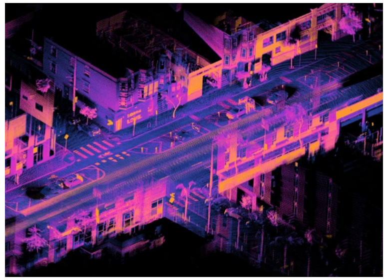
- Sensor Fusion: combine the advantages

Target:

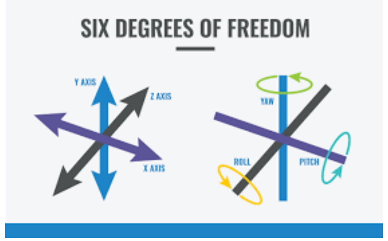
- High frequency
- Acceptable cost
- High accuracy

Sensor	Advantage	Disadvantage
IMU	High frequency	Low accuracy
ToF / Image	High adaptability	Low frequency
Lidar	High accuracy	High cost

AGV



LiDAR



IMU

Requirements and Specifications

Customer Requirement:

- High Accuracy:

  - Reliable location and angle estimation

- High Frequency:

  - Localization during movement

- Acceptable cost

Engineering specification	Target value
Delay of communication	3 [ms]
Response time of lidar	100 [ms]
Precision of the lidar	0.5 [mm]
Resolution ratio of camera	320×640 [dpi]
Response time of IMU	10 [ms]
Voltage of the battery	11.4 [V]
Torque of the motor	3 [N·m]
Precision of estimated location	**10 [cm]**
Precision of estimated angle	**10 [°]**
Response time of estimation	**10 [ms]**
Total cost	**3000 [RMB]**

Engineering design

Specification:

Frequency > 100Hz ; Error < 10cm

Calculation:

$$|\sigma_X(10T)|_\infty = |\sigma_{10Hz}|_\infty$$
$$|A|_\infty = |\sigma_{100Hz}|_\infty$$
$$|\sigma_X(10T+1)|_\infty = |A \cdot \sigma_X(10T)|_\infty \leq |\sigma_X(10T)|_\infty \cdot |A|_\infty$$
$$|\sigma_X(10T+n+1)|_\infty = |A \cdot \sigma_X(10T+n)|_\infty \leq |\sigma_X(10T+n)|_\infty + |A|_\infty$$
$$|\sigma_X(10T+9)|_\infty \leq 9|A|_\infty + |\sigma_X(10T)|_\infty$$
$$10[cm] \geq 9|A|_\infty + |\sigma_X(10T)|_\infty \geq |\sigma_X(10T+9)|_\infty$$

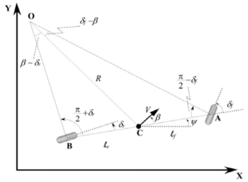
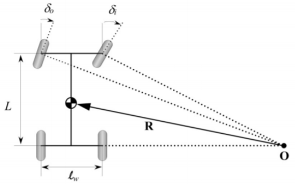
Therefore, we want

$$|\sigma_{100Hz}|_\infty = |A|_\infty \leq 1.1[cm]$$
$$|\sigma_{10Hz}|_\infty = |\sigma_X(10T)|_\infty \leq 0.025[cm]$$

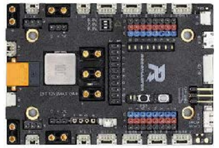
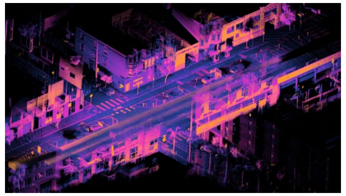
Concept Generation and Selection

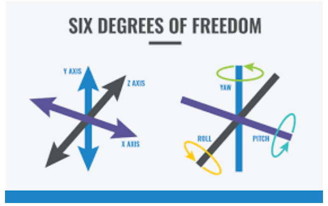
AGV Sensor Fusion System

- Lateral vehicle motion
- Computation and control unit
- Low frequency navigation
- High frequency navigation

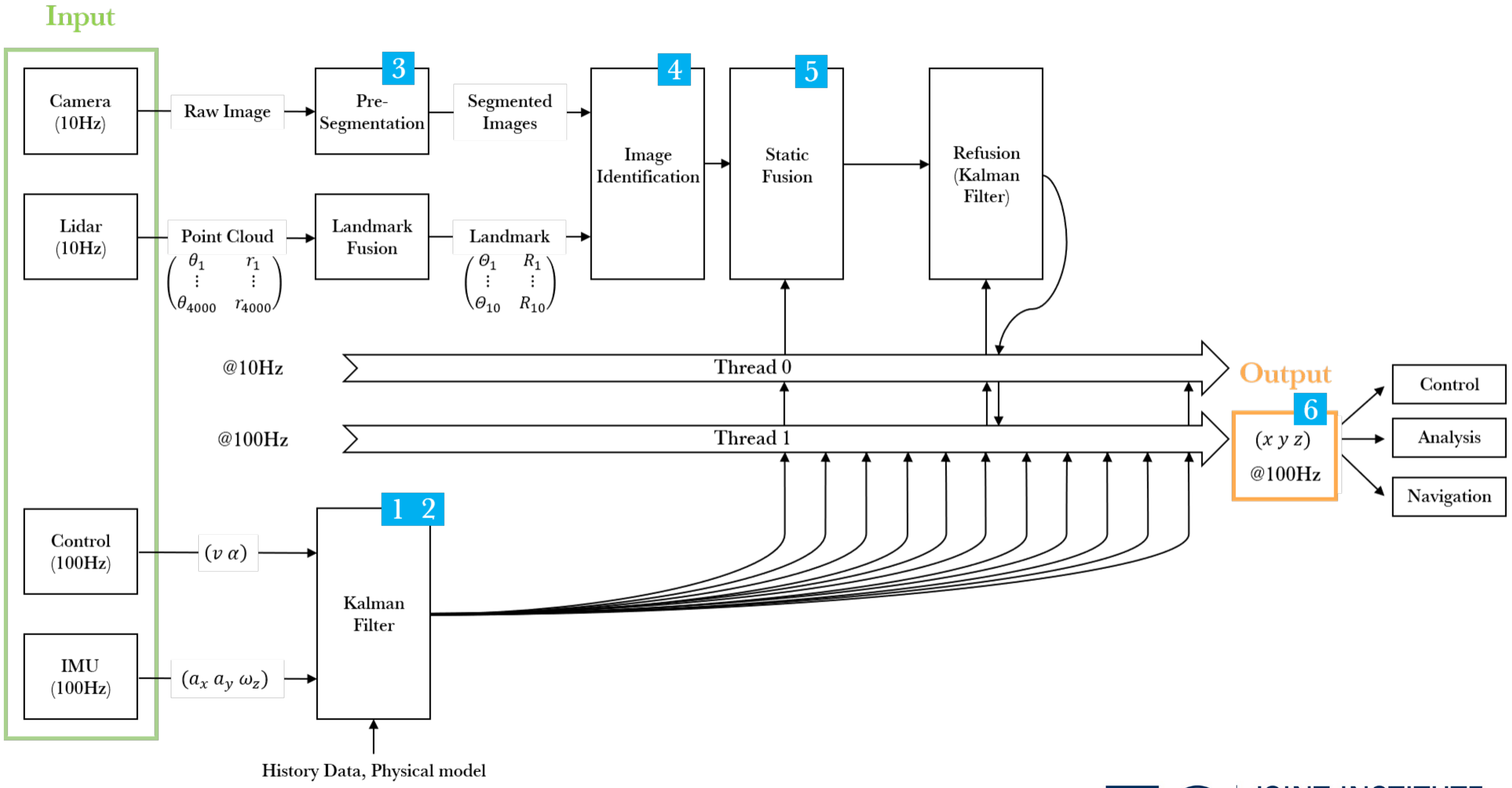







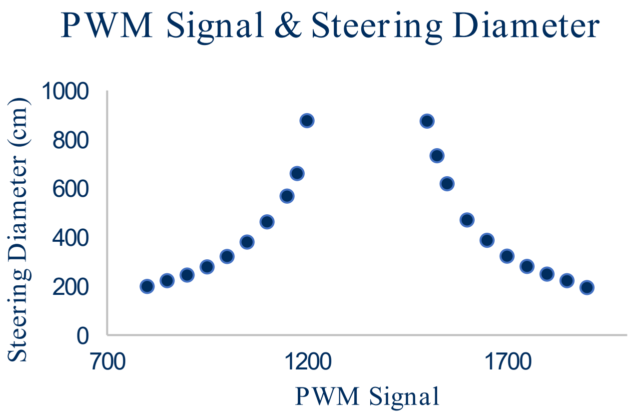
Design Details

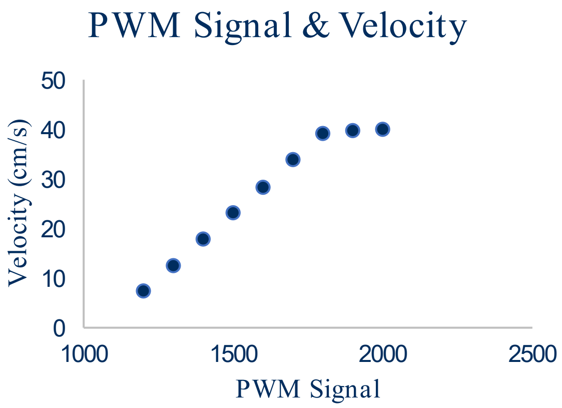


Experiment 1

System Identification

- Clarify the relation between
  - 1. PWM signal & Velocity
  - 2. PWM signal & Steering angle

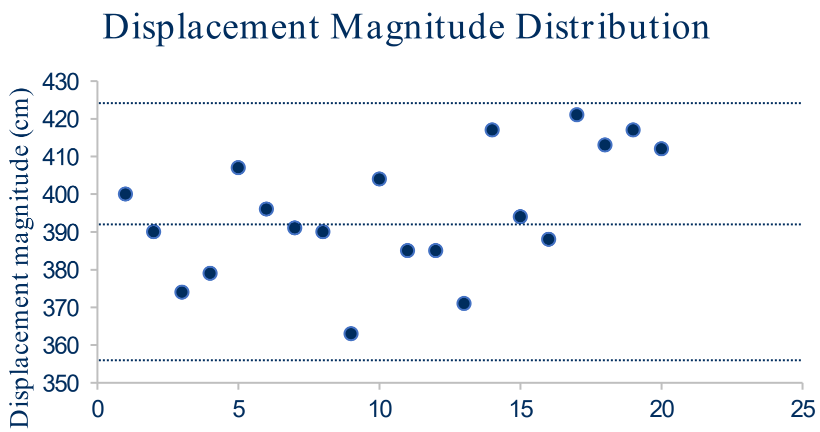




Experiment 2

Kalman Filter Error Estimation

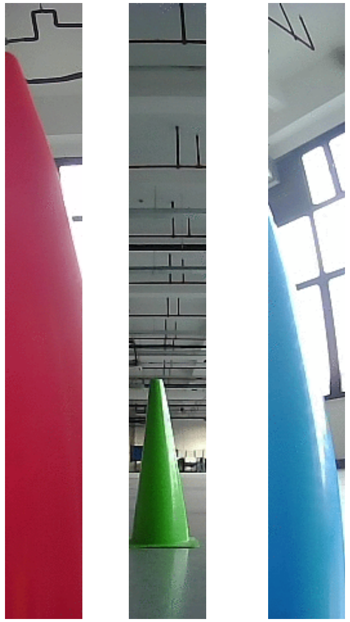
- Evaluate the Kalman Filter Error after 10s running



Experiment 3

Picture Segmentation

- Divide picture into ten equal parts vertically.
- Derive x-axis position in pictures with angle and distance information.



Experiment 4

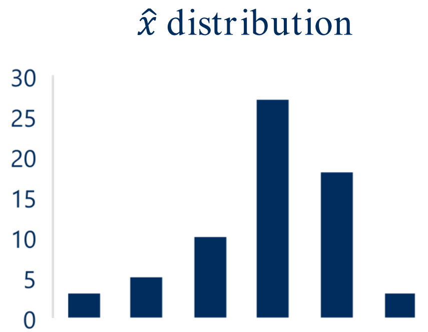
Image Identification

- Built training set of 6000 images and test set of 2000 images.
- Take into consideration many boundary conditions (e.g., extreme light).

Experiment 5

Static Triangulation

- Test when AGV is still.
- Apply triangulation with each two landmarks and make localization.



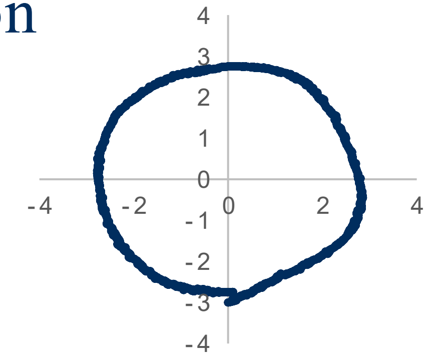
$\sigma_{x,10Hz} = 0.025\ [cm]$

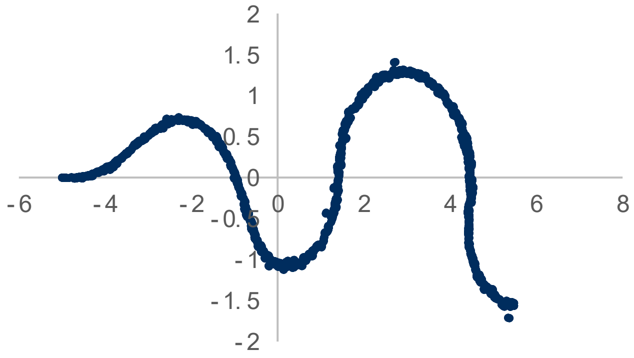
$\sigma_{y,10Hz} = 0.005\ [cm]$

Experiment 6

Dynamic Localization Error Estimation

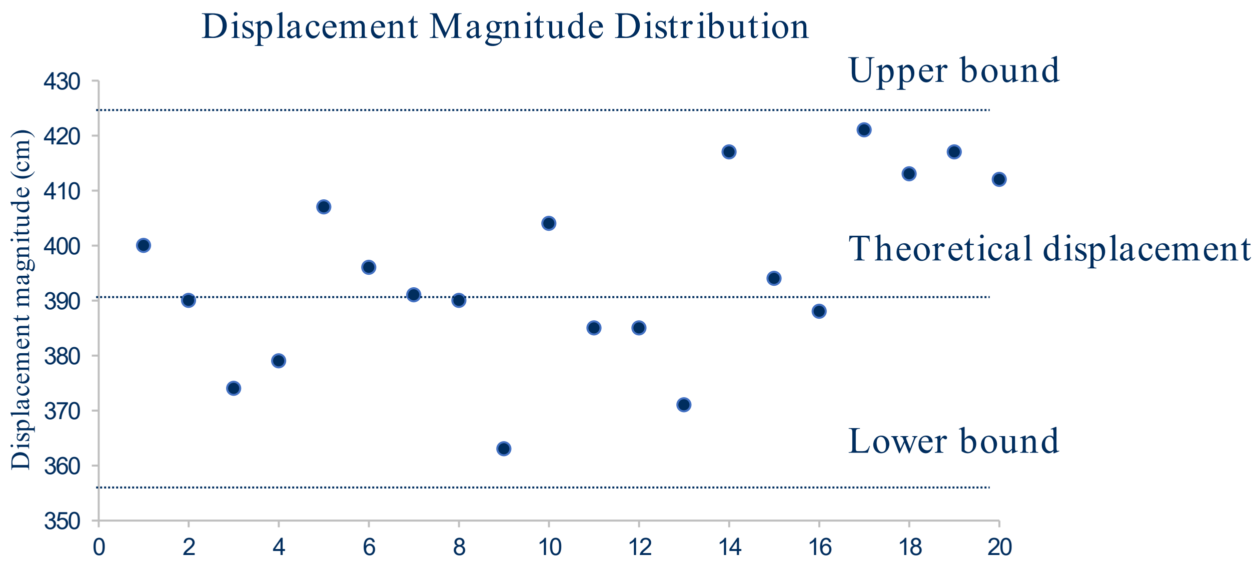
- Test when AGV is moving.
- Analyze dynamic properties of the localization.
- Verify validation of the project and satisfaction of specifications.





Verification

Experiment 2 - Kalman Filter Error Estimation



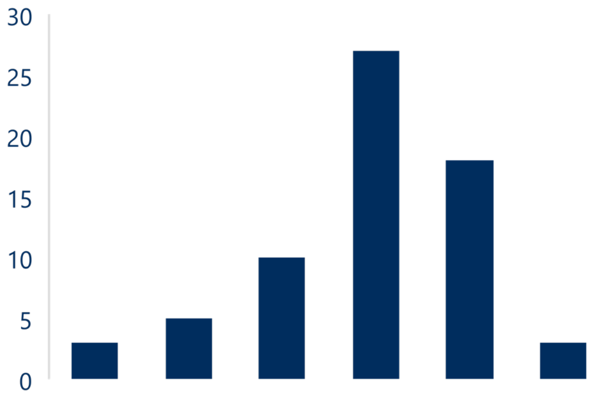
$$|A|_\infty \ (error\ in\ 10ms) \leq 1.1\ [cm]$$
$$err_A = \sqrt{(|A|_\infty)^2 \times 1000} = 34.79\ [cm]$$

- After running 10s, the theoretical displacement is 390.25 cm.

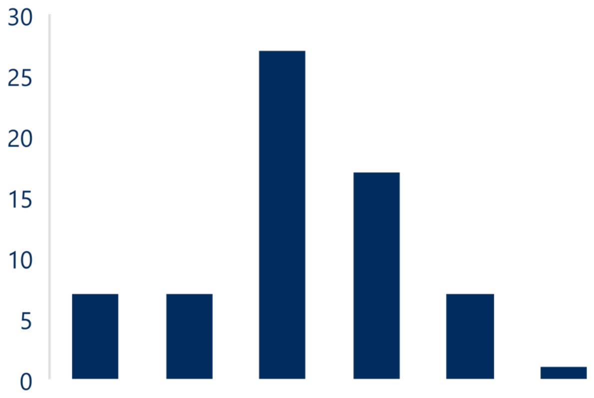
Verification

Experiment 5 – Static Triangulation

$\hat{x}$ distribution



$\hat{y}$ distribution



The standard deviation of the triangulation result is:

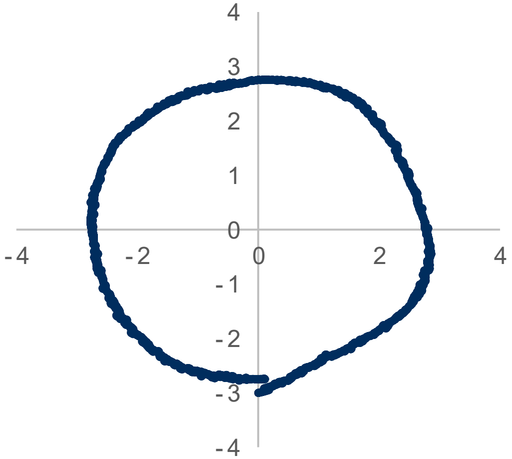
$$\sigma_{x,10Hz} = 0.0233[m] \text{ and } \sigma_{y,10Hz} = 0.0058[m]$$

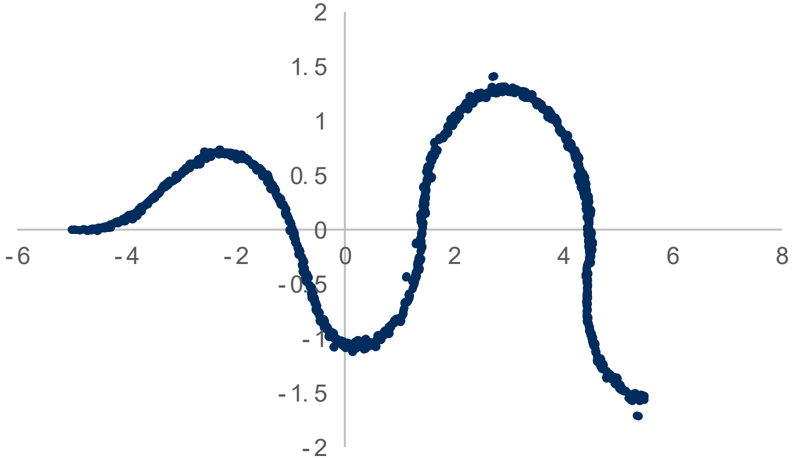
Our specification is:

$$|\sigma_{10Hz}|_\infty = |\sigma_X(10T)|_\infty = 0.025[m]$$

Verification

Experiment 6 – Dynamic Localization Error Estimation

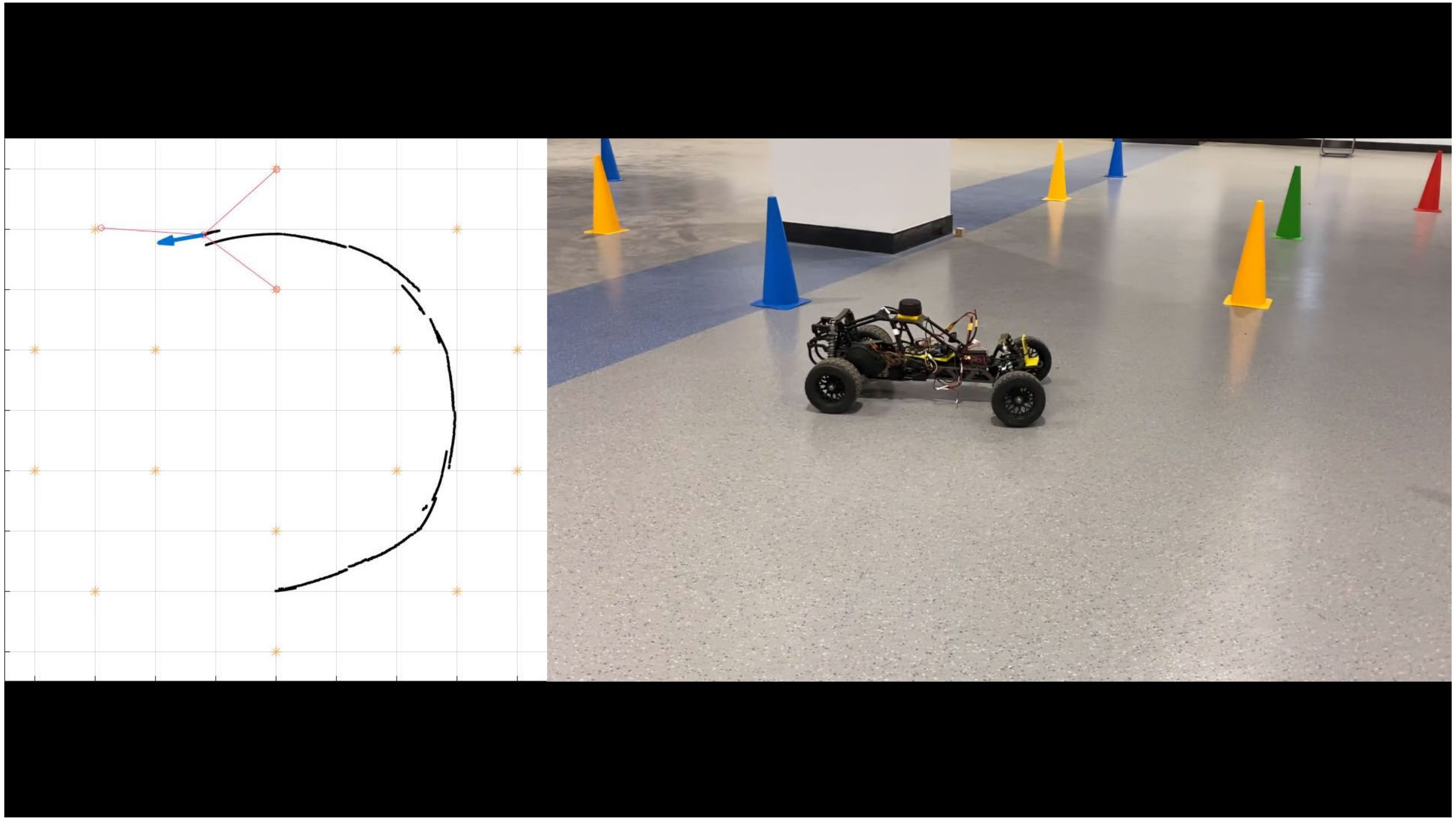




Two of moving tracks are tested: circle and sine wave.

	Average Error (m)	Standard Deviation (m)
Circle	0.048	0.024
Sine	0.060	0.026

Operation Demo



Discussion

Strength

- Estimation is quick and accurate.
- Calculation burden is not heavy.
- Total cost is customer friendly.

Improvement

- Develop mapping function
- Use more sensors
- Apply low-frequency filter

Weakness

- Pre-established map is needed
- Dynamic localization error exists

Challenge

- Model adaptation
- High frequency

Conclusion

Objective:

- Position, Orientation, Response time, Total cost

Design solution:

- Kalman Filter, Image identification, Triangulation method

Lessons:

- Start as early as possible
- Discard infeasible plan and find a better solution

Reference

S. Quan and J. Chen, "Agv localization based on odometry and lidar," in *2019 2nd World Conference on Mechanical Engineering and Intelligent Manufacturing (WCMEIM)*, pp. 483–486, 2019.

P. Yuan, D. Chen, T. Wang, F. Ma, H. Ren, Y. Liu, and H. Tan, "Agv system based on multi-sensor information fusion," in *2014 International Symposium on Computer, Consumer and Control*, pp. 900–905, 2014.

L. Zhongming, W. Xun, and S. Zhiyuan, "A navigation method of information fusion and mutual aid based on map for logistic agv," in *2014 Sixth International Conference on Measuring Technology and Mechatronics Automation*, pp. 21–24, 2014.

S. Zhou, G. Cheng, Q. Meng, H. Lin, Z. Du, and F. Wang, "Development of multi-sensor information fusion and agv navigation system," in *2020 IEEE 4th Information Technology, Networking, Electronic and Automation Control Conference (ITNEC)*, vol. 1, pp. 2043–2046, 2020.

Z. Li, Z. Su, and T. Yang, "Design of intelligent mobile robot positioning algorithm based on imu/odometer/lidar," in *2019 International Conference on Sensing, Diagnostics, Prognostics, and Control (SDPC)*, pp. 627–631, 2019.

L. Lynch, T. Newe, J. Clifford, J. Coleman, J. Walsh, and D. Toal, "Automated ground vehicle (agv) and sensor technologies- a review," in *2018 12th International Conference on Sensing Technology (ICST)*, pp. 347–352, 2018.

M. N. Tamara, A. Darmawan, N. Tamami, C. sugianto, S. Kuswadi, and B. Pramujati, "Electronics system design for low cost agv type forklift," in *2018 International Conference on Applied Science and Technology (iCAST)*, pp. 464–469, 2018.

T. Miyamoto and K. Inoue, "Random search for dispatch and conflict-free routing problem of capacitated agv systems," in *2013 IEEE International Conference on Systems, Man, and Cybernetics*, pp. 1611–1615, 2013.

Reference

B. Xu and D. Wang, "Magnetic locating AGV navigation based on kalman filter and pid control," in *2018 Chinese Automation Congress (CAC)*, pp. 2509–2512, 2018.

E. Shi, Z. Wang, X. Huang, and Y. Huang, "Study on AGV posture estimating based on distributed kalman fusion for multi-sensor," in *2009 IEEE International Conference on Robotics and Biomimetics (ROBIO)*, pp. 1219–1223, 2009.

S. Quan and J. Chen, "AGV localization based on odometry and lidar," in *2019 2nd World Conference on Mechanical Engineering and Intelligent Manufacturing (WCMEIM)*, pp. 483–486, 2019.

J. Martinez, "Agvs: navigation systems."

Youtube, "Vision based navigation and localization."

C. Pao, "The importance of imu motion sensors."

Baidu, "Automated guided vehicle."

A. Robotics, "Amazon robotics."

Egemin-automation.com, "Dematic, automation solutions for distribution, logistics, food, pharmaceuticals, oil & gas and infrastructure."

Thanks for Listening

Q&A