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Cooperative Tracking of People Using Networked LiDARs

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Presenter

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- He is currently working as a Professor with Department of Intelligent Information Engineering and Deputy Director of Mobility Research Center in Doshisha University, Kyoto, Japan.
- His research interests and expertise include LiDAR-based sensing, sensor fusion, and sensor network with applications in active safety and autonomous driving of vehicles and mobile robots.

Doshisha University

Agenda

1. Motivation

2. Experimental system

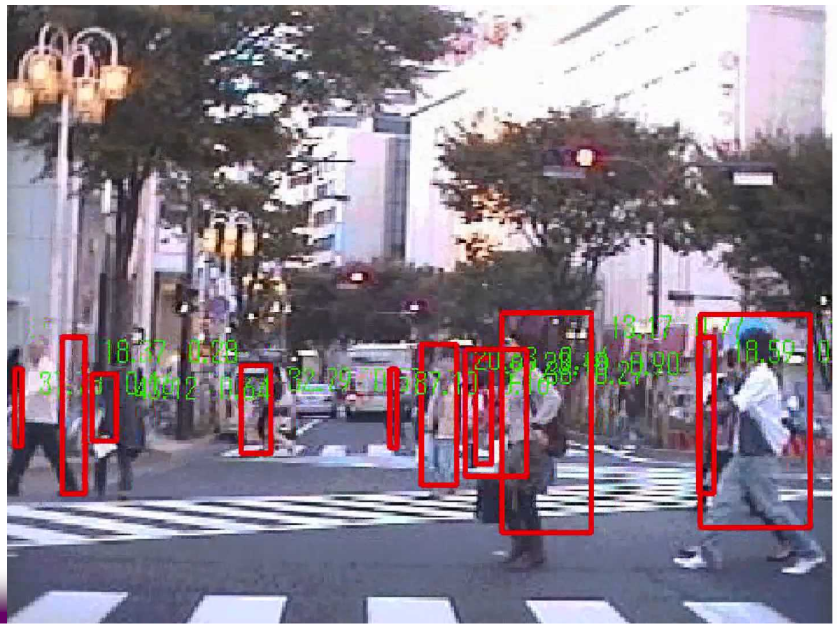
3. People detection and tracking

4. Simulation experiments

5. Conclusion and future work

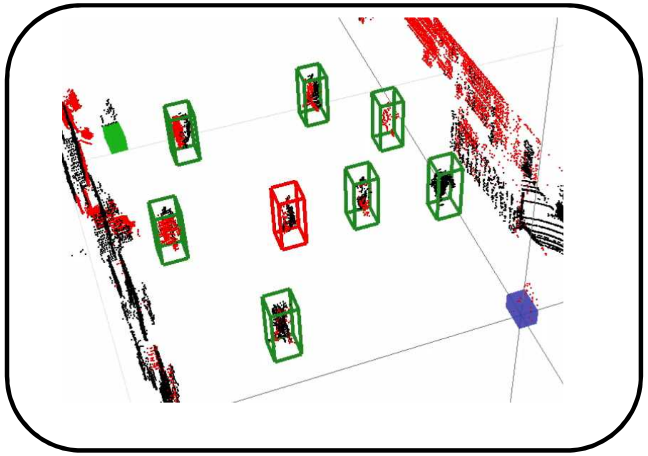
Motivation (1)

- Tracking (estimation of motion and behaviors) of people using ground LiDAR is an important topic in Intelligent Transportation Systems (ITS), security, and many other applications.
- Many LiDAR-based people trackers have been developed.
- Cooperative people tracking by multiple LiDARs allocated at different locations can improve the tracking reliability, because even if people are occluded or located outside a LiDAR sensing area, the cooperative tracking can recognize people by sharing the tracking data from nearby other LiDARs.



Motivation (2)

- As an application of cooperative tracking to ITS domains, we proposed a cooperative people tracker using networked multiple ground LiDARs in an intersection environment [Nakahira et al., 2019].
- The cooperative people tracker using distributed interacting multimodel (DIMM)-based estimator
  - recognized people positions, velocities, and behaviors, such as stopping, walking, and suddenly rushing out, and
  - employed a data fusion in a distributed manner without any central servers. It then provided system robustness and scalability compared with the centralized data fusion.



T. Nakahira, M. Hashimoto, and K. Takahashi, "Cooperative people tracking using multiple ground lidars based on distributed interacting multimodel estimator," Proc. of 6th Int. Conf. on Control, Decision and information Technologies, 2019.

Motivation (3)

- However, in our previous study, people could be tracked using only two LiDARs.
- In this study, DIMM-based cooperative tracking of people is presented using three LiDARs.
- The contributions of this study are as follows:
  - A DIMM-based cooperative people tracker using three LiDARs is designed in two different network topologies (ring and line network topologies). The tracking method is applicable to four or more LiDARs systems in any network topology.
  - The tracking performance and computational effort of the presented DIMM-based tracker are quantitatively evaluated by comparing conventional CIMM-based and Kalman filter-based trackers.

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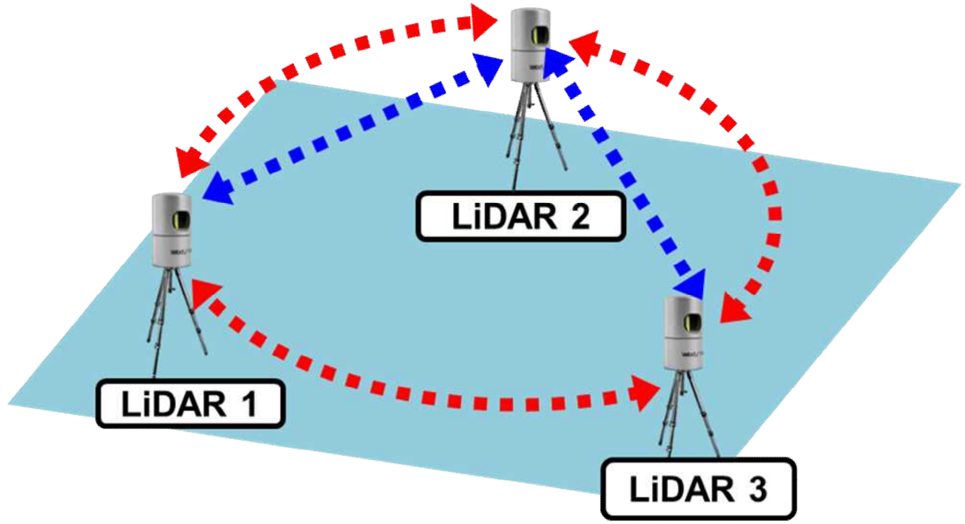
Experimental system

Specification of Velodyne LiDAR

- Layer : 32
- Scanning frequency : 10 Hz
- Maximum range : 50 m
- Horizontal view angle : 360°
- Vertical view angle : 41.3 °



LiDAR network topology

- Two network topologies are considered for exchanging information among LiDARs:
  - Ring network topology, in which each LiDAR is connected to two other adjacent LiDARs.
  - Line network topology: LiDARs 1 and 2 and LiDARs 2 and 3 are connected.
- For four or more LiDARs, similar to the case of three LiDARs, each LiDAR is connected to two other LiDARs on both sides in a ring network topology, whereas, in a line network topology, only the LiDARs at both ends of the line are connected to one adjacent LiDAR, and other LiDARs are connected to the two LiDARs.

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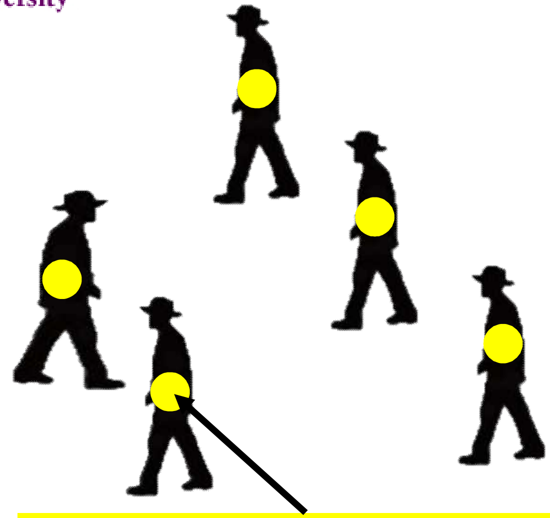
Basic sequence of people detection and tracking



Geometric center of people measurements

LiDAR image

Detection

Mapping onto elevation map

Background subtraction

LiDAR measurements related to people (people measurements)

Clustering

Geometric center of people measurements

Tracking

Global-nearest-neighbor (GNN) based data association

(One-to-one matching of the people and the people measurements)

Interacting mutimodel* (IMM) estimator

(Estimate of people position, velocity and behaviour)

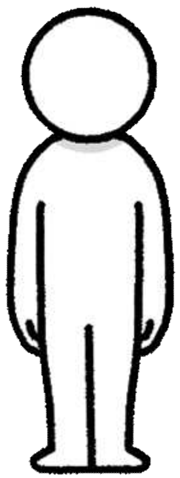
Track handling

(Improvement of tracking performance)

* H. A. P. Blom and Y. Bar-Shalom, "The Interacting Multiple Model Algorithm for Systems with Markovian Switching Coefficient," IEEE Transaction. on Aerospace and Electronic Systems, Vol. 33, No. 8, pp. 780–783, 1988.

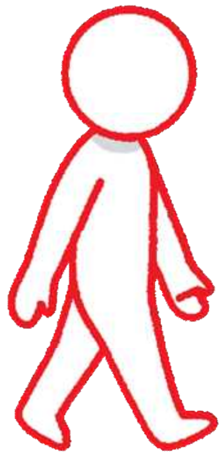
Motion model

To accurately track people in an intersection environment, three motion models of a person are considered.



Stop model

Person stops.



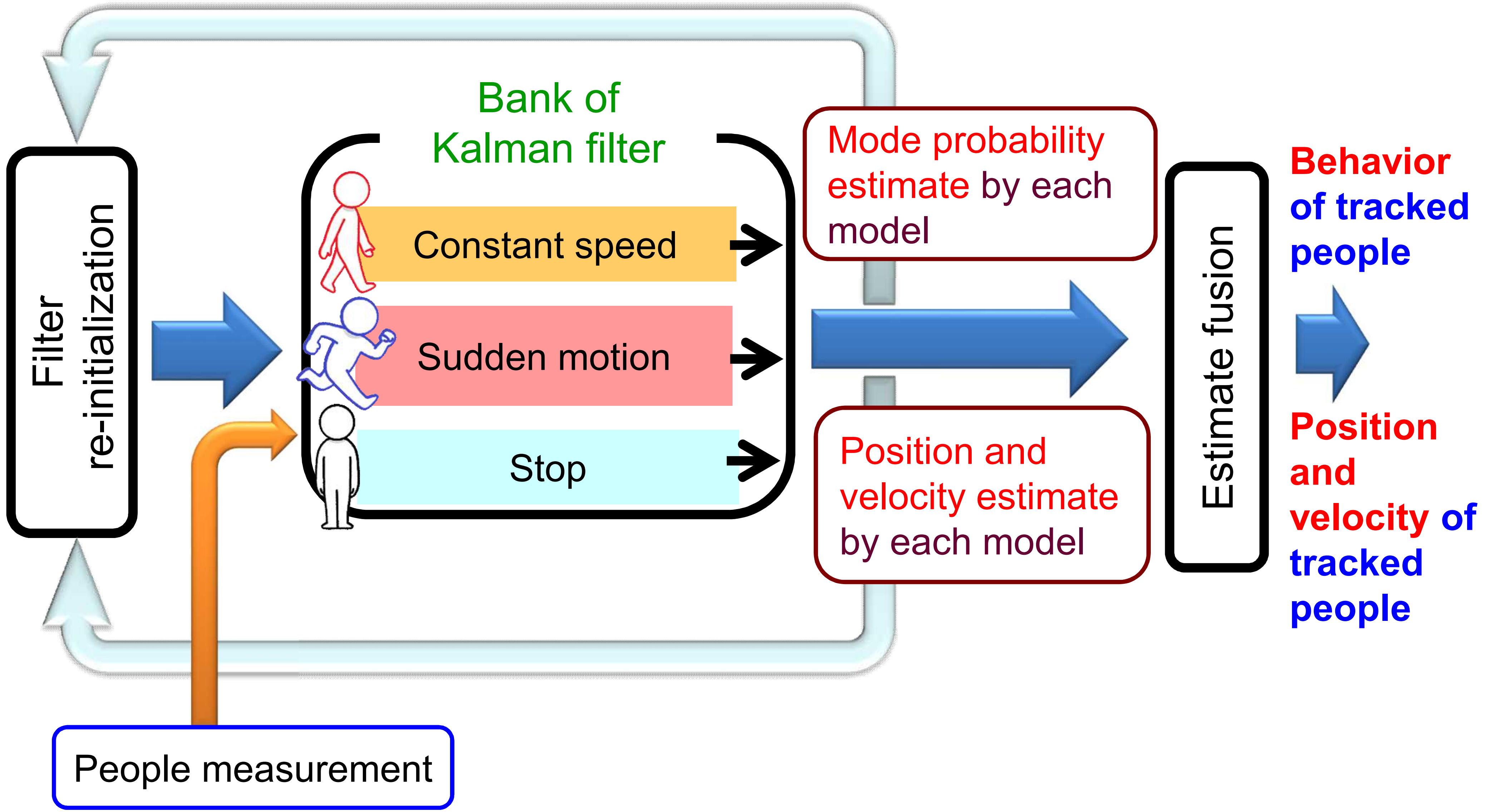
Constant speed model

Person walks or runs at an almost constant speed.

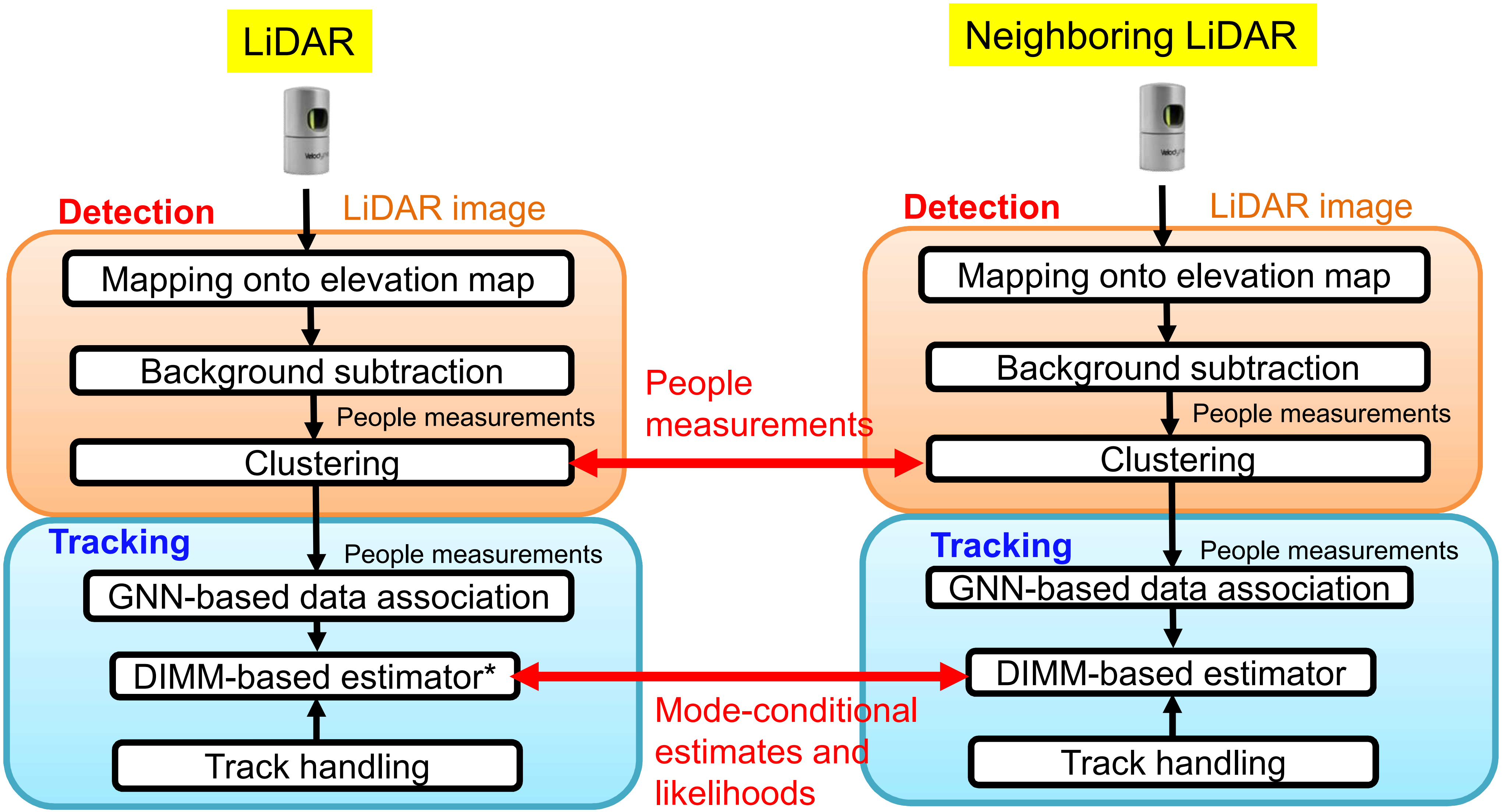
Sudden motion model

Person suddenly starts or suddenly stops.

Sequence of interacting-multimodel (IMM) estimator



Sequence of our cooperative people tracker using distributed interacting-multimodel (DIMM) based estimator



* W. Li and Y. Jia: “Distributed Estimation for Markov Jump Systems via Diffusion Strategies,” IEEE Transactions on Aerospace and Electronic Systems, Vol.53, pp. 448－460, 2017.

Track handling

When tracking people, various situations would arise, such as

- new people come in the sensing area of LiDAR,
- tracked people leave the sensing area,
- people are occluded by other people, and
- people are in close proximity for a long period of time.

To improve the tracking performance in such situations, the following rule-based methods are implemented:

- Track initiation
- Track termination
- Track merging and splitting

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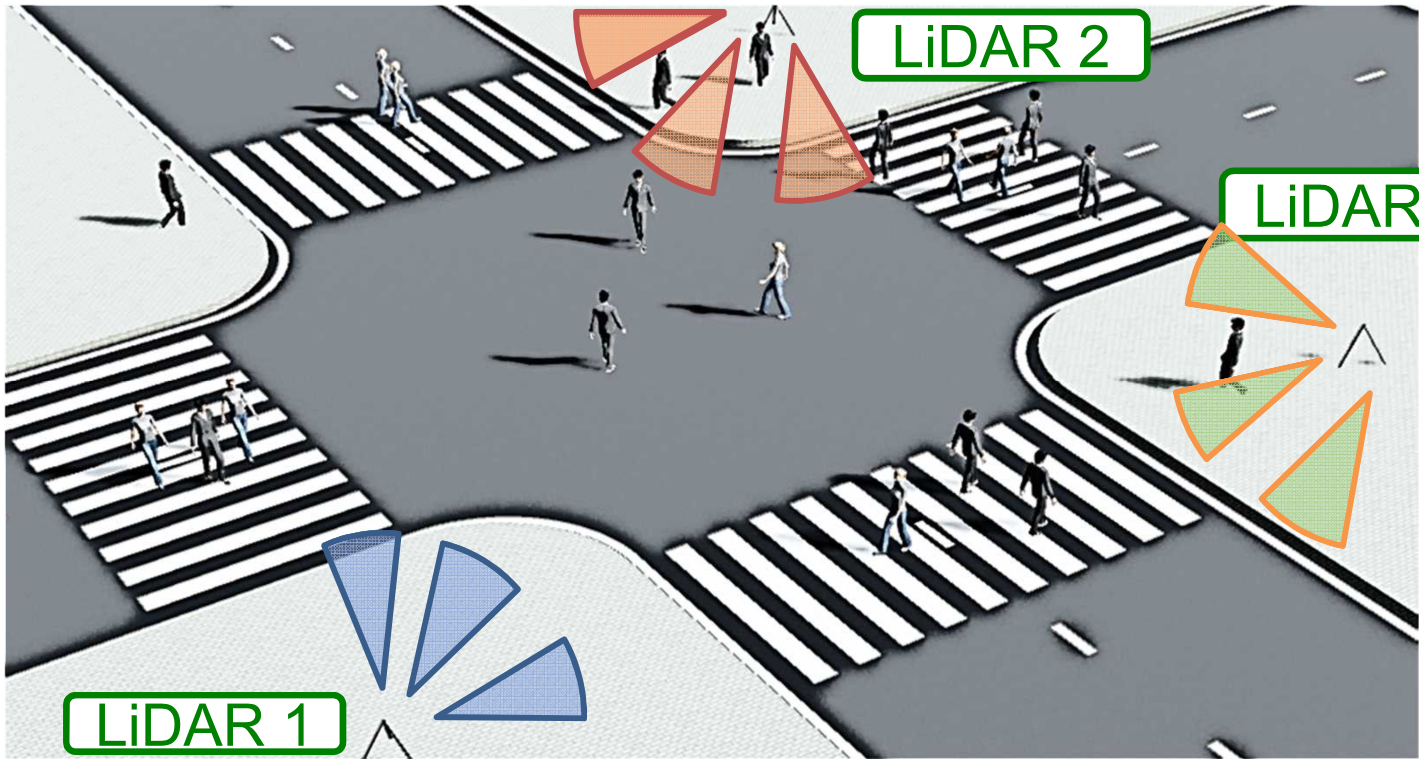
Simulation experiments (1)

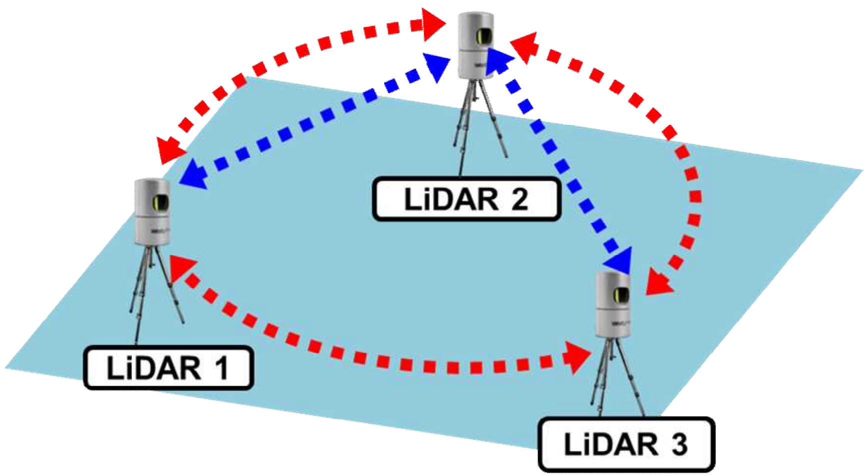
- 20 people in an intersection environment are tracked by three LiDARs.
- People are walking, running, stopping, and sudden start/stop.
- People motions and LiDAR measurement data are generated by a simulator (Siemens Prescan).



Simulation experiments (2)

The tracking performance is evaluated for the following four cases:

- Case 1: Our distributed IMM (DIMM)-based tracker in a ring network topology,
- Case 2: Our DIMM-based tracker in a line network topology,
- Case 3: Centralized IMM (CIMM)-based tracker, in which three LiDARs detect people based on the background subtraction method, detected people measurements are sent to the central server, and people are tracked on the central server, and
- Case 4: Distributed Kalman filter (DKF)-based tracker using a single motion model (constant speed model) in a ring network topology.



Simulation results: Tracking error (1)

Case 1	Case 2	Case 3	Case 4
0.31	+8.1 %	-1.2 %	+61.2 %

- In this table, the result for case 1 shows the root-mean-squared error in estimates of 20 people.
- The results for cases 2, 3, and 4 represent the percentage of the tracking error to that in case 1.

The positive sign (+) indicates that the tracking error is larger than that for case 1, whereas the negative sign (-) indicates the opposite.

Simulation results: Tracking error (2)

Case 1	Case 2	Case 3	Case 4
0.31	+8.1 %	-1.2 %	+61.2 %

- The tracking error in case 2 (line network topology) is approximately 8 % larger than that in case 1 (ring network topology).

  This is because in case 1, each LiDAR exchanges detection and tracking information with two LiDARs located at both sides, whereas, in case 2, LiDARs 1 and 3 exchange information only with LiDAR 2.

- Since the difference in the tracking error between case 1 (DIMM-based tracker) and case 3 (CMM-based tracker) is approximately 1 %, both trackers can track people at almost the same degree of accuracy.

- The tracking performance in case 4 (DKF-based tracker) is approximately 61% worse than that in case 1 (DIMM-based tracker). This is because, in case 4, a constant-speed model is employed as the motion model of a person, and the tracking error increases when the person performs a sudden acceleration motion.

Simulation results: Computational time

	LiDAR 1	LiDAR 2	LiDAR 3
Case 1	114.5 ms	103.9 ms	104.5 ms
Case 2	119.7 ms	109.1 ms	126.5 ms
Case 3	113.4 ms		

- To check the computational time, a computer is used with the specifications: Windows 10 Pro OS, Intel(R) Core (TM) i7-8565U @1.80 GHz CPU, 16 GB RAM, and C++ software language.
- The computation time indicates the time required to detect and track people from the LiDAR scan data obtained within a scan.

  Note that the computation time in case 3 (CIMM-based tracking) is the sum of the computation times in LiDAR 1 and the central server.
- The computation time is almost the same for all the cases.

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Conclusion and future work

- The cooperative people tracker using three ground LiDARs was designed based on distributed interacting-multimodel (DIMM)-based estimator.
- Simulation results of tracking of 20 people showed the performance of the DIMM-based tracker by comparison with the centralized interacting-multimodel (CIMM) and decentralized Kalman filter (DKF)-based estimators.

As our future studies,

- The presented method will be evaluated through real experiments.
- A machine-learning-based method will be employed to improve the performance of people detection in crowded environments.