Lecture 6 | SLAM

Secure Autonomous Systems

CSCI 6907/3907 86

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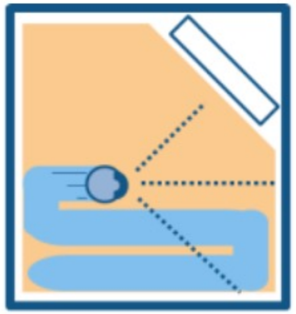
Prof. Sibin Mohan

https://bit.ly/secureauto-spring24

Simultaneous Localization and Mapping [SLAM]

Without



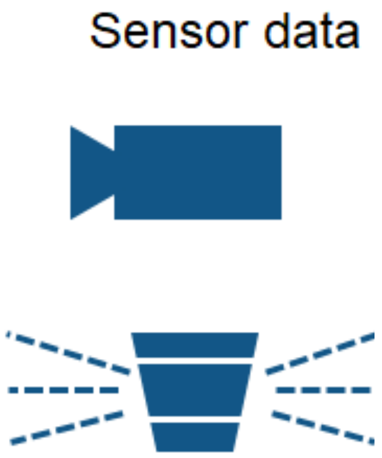
With

BUILD A MAP

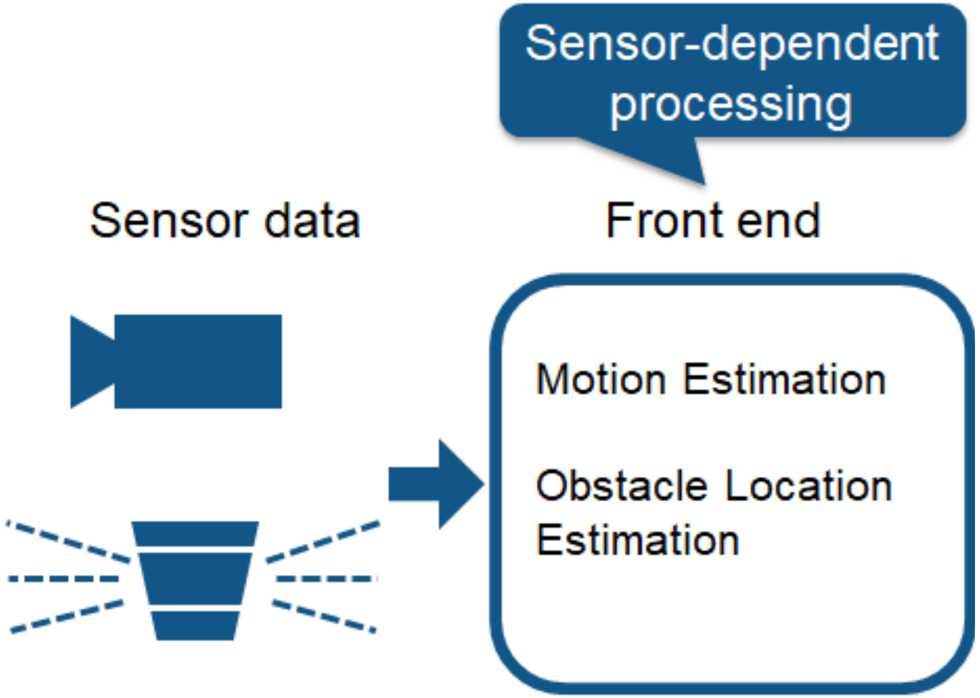
LOCALIZE YOUR VEHICLE

Used for path planning, obstacle avoidance

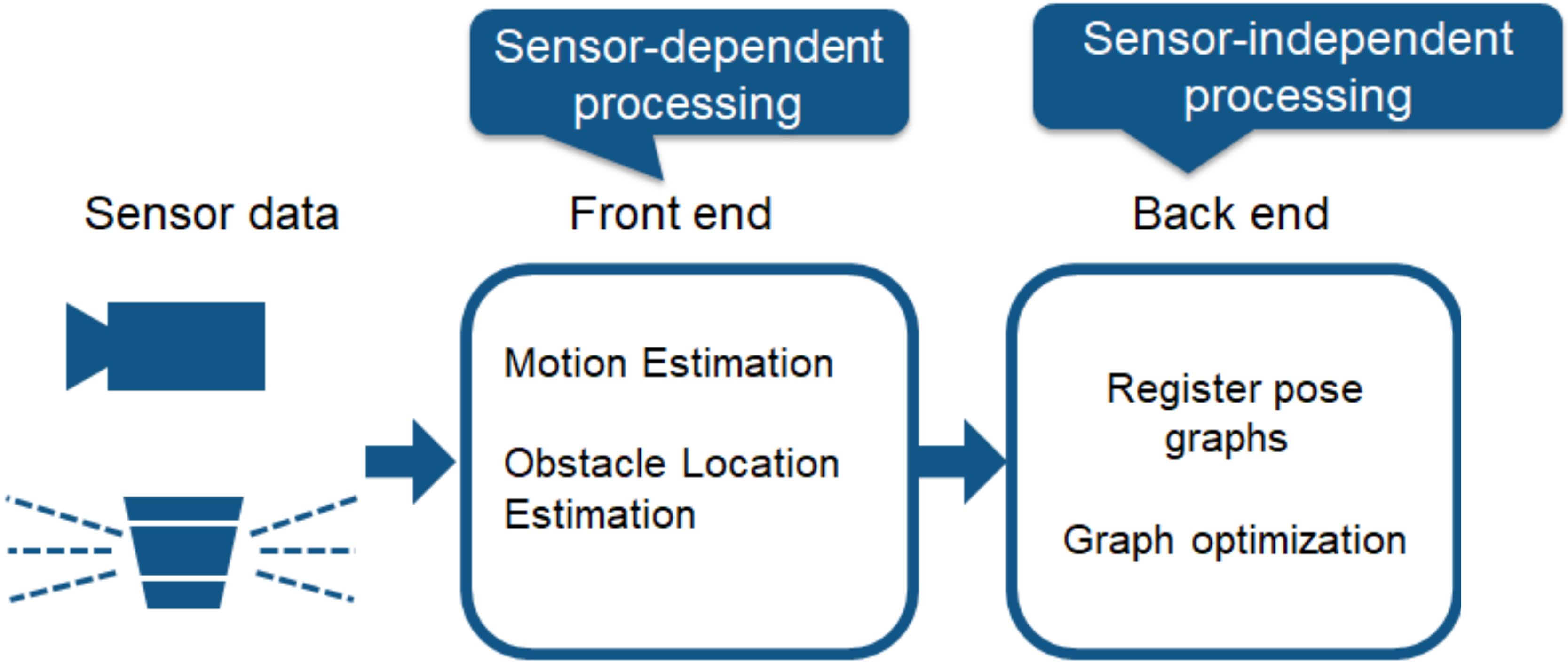
SLAM Processing Workflow



SLAM Processing Workflow

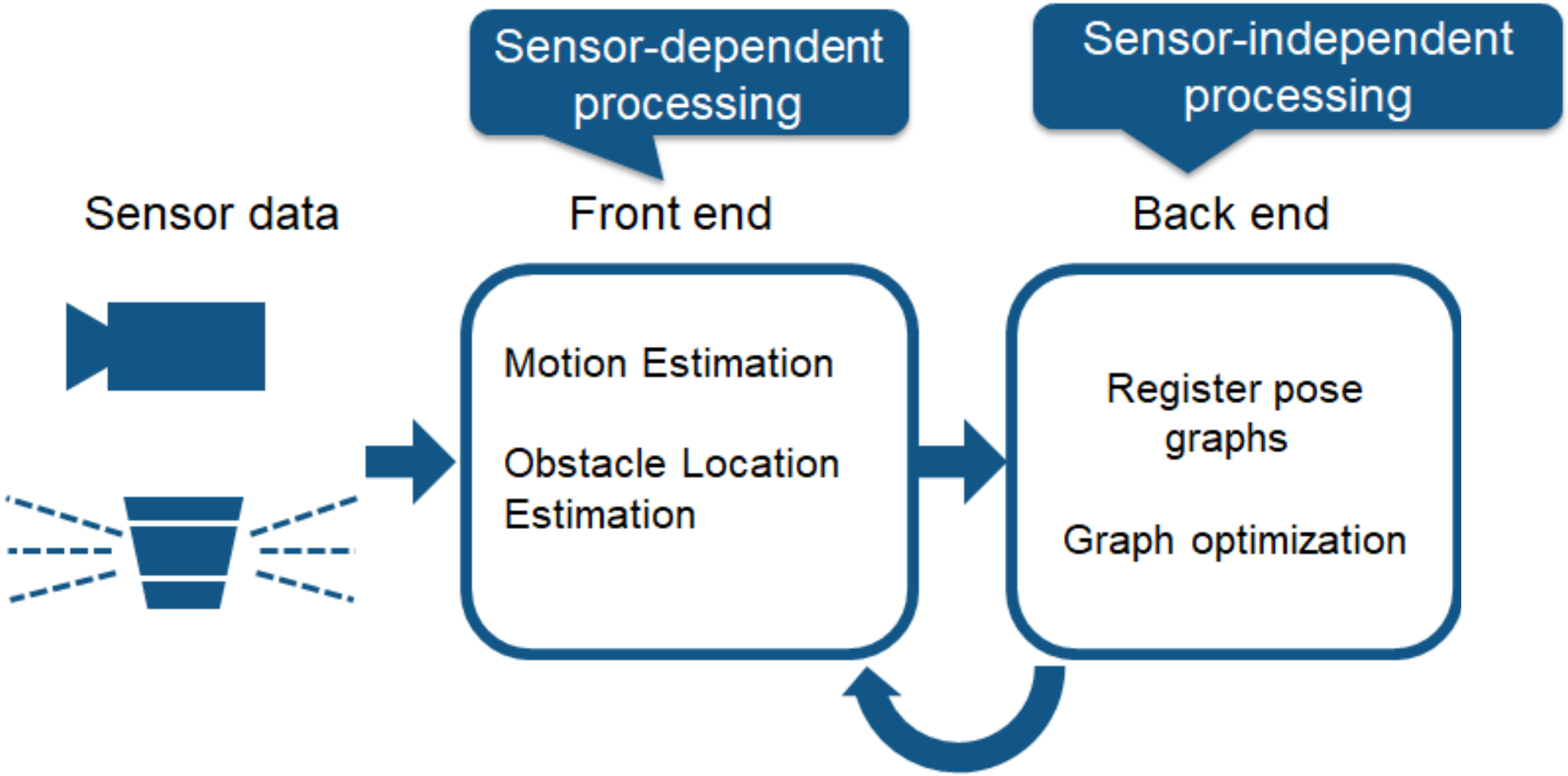


SLAM Processing Workflow

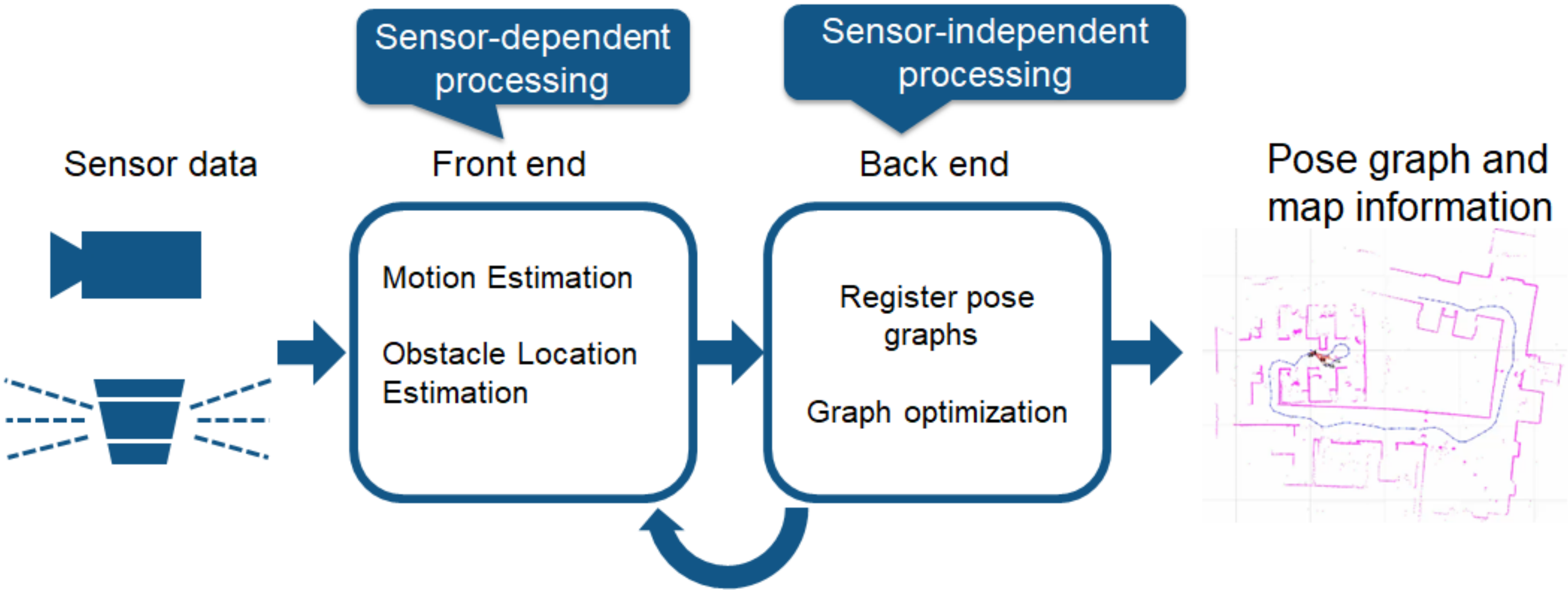


“**pose**” → position+orientation

SLAM Processing Workflow

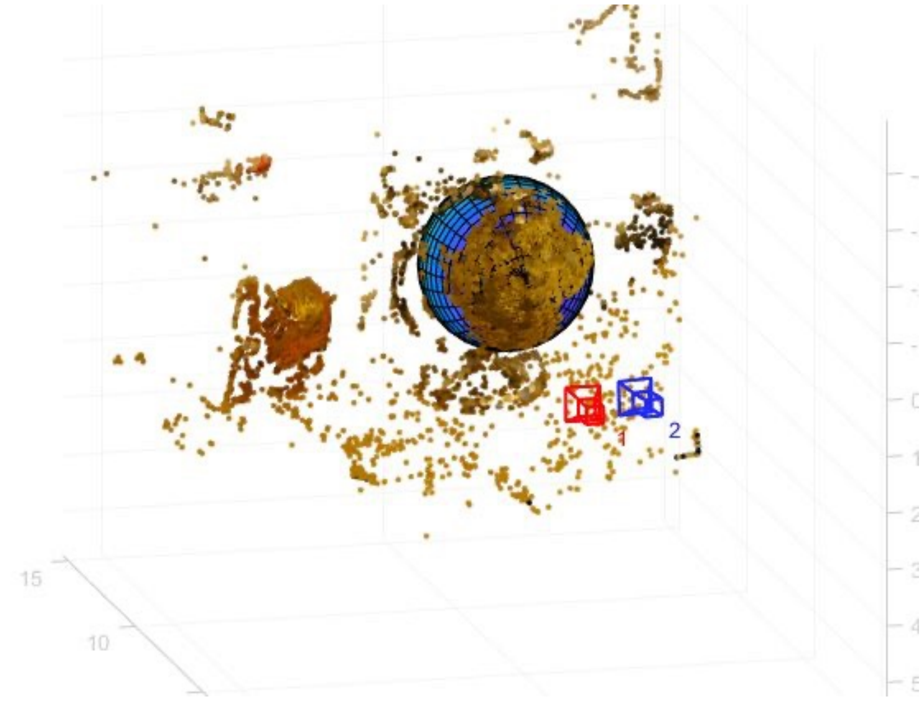


SLAM Processing Workflow

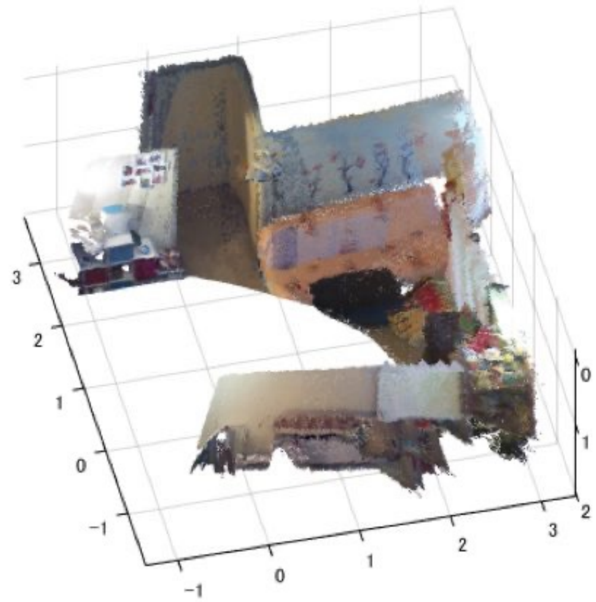


Types of SLAM

- Visual SLAM (**vSLAM**) uses **cameras**
  - Sparse methods match feature points of images [PTAM, ORB_SLAM]
  - Dense methods use overall brightness of images [DTAM, LSD- SLAM, DSO, SVO]

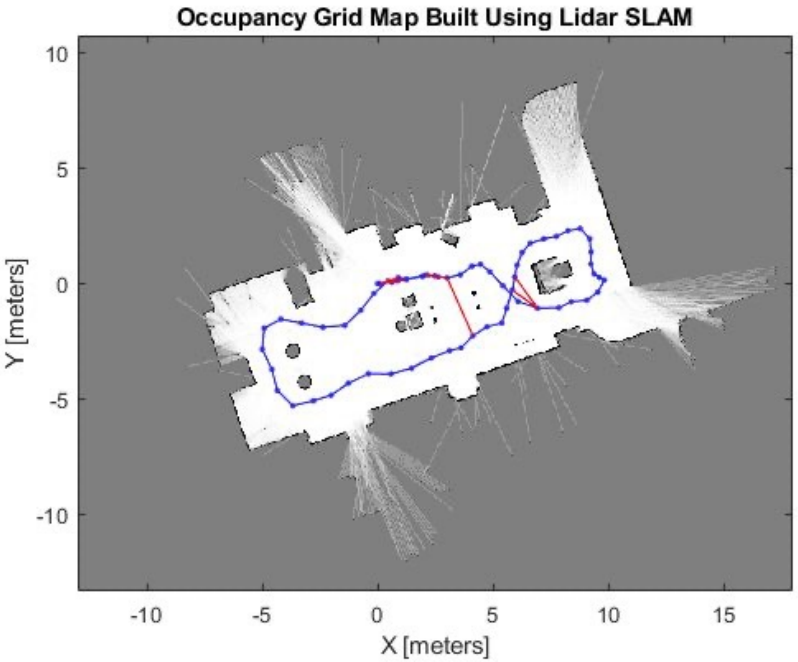


Structure from Motion

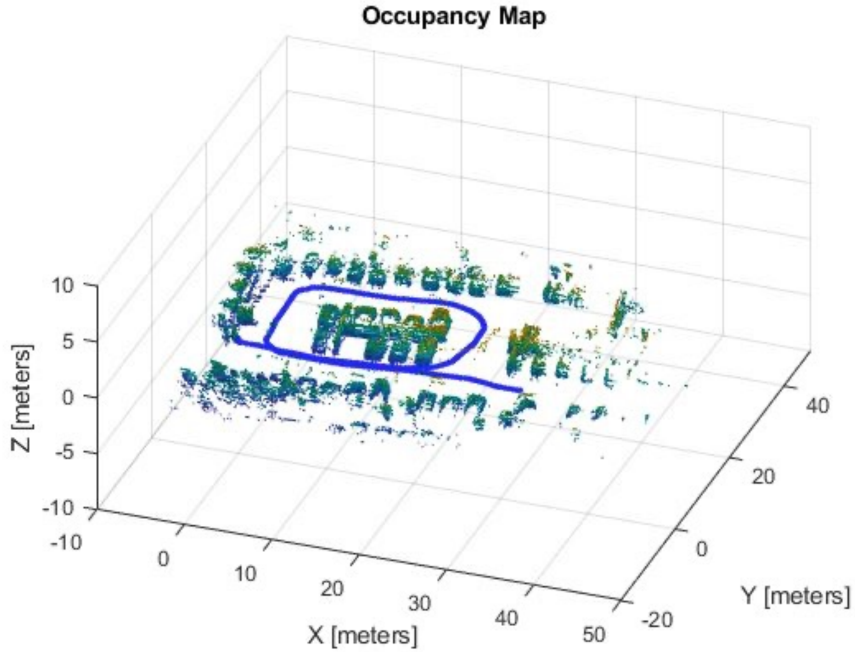

Point cloud registration

Types of SLAM | LiDAR SLAM

- Laser point cloud provides **high-precision distance measurements**
- Not as finely detailed as camera images
- Environments with fewer obstacles ➔ less precision
- May require **fusion** with other sensors (e.g., GPS, odometry)



SLAM with 2D LiDAR



SLAM with 3D LiDAR

SLAM Components

LANDMARK ASSOCIATION

DATA ASSOCIATION

STATE ESTIMATION

STATE UPDATE

LANDMARK UPDATE

SLAM Details | The Hardware

- Mobile robot → e.g., indoor robot
- Range measurement device → e.g., LiDAR, RADAR, Sonar, etc.

SLAM Steps | Details

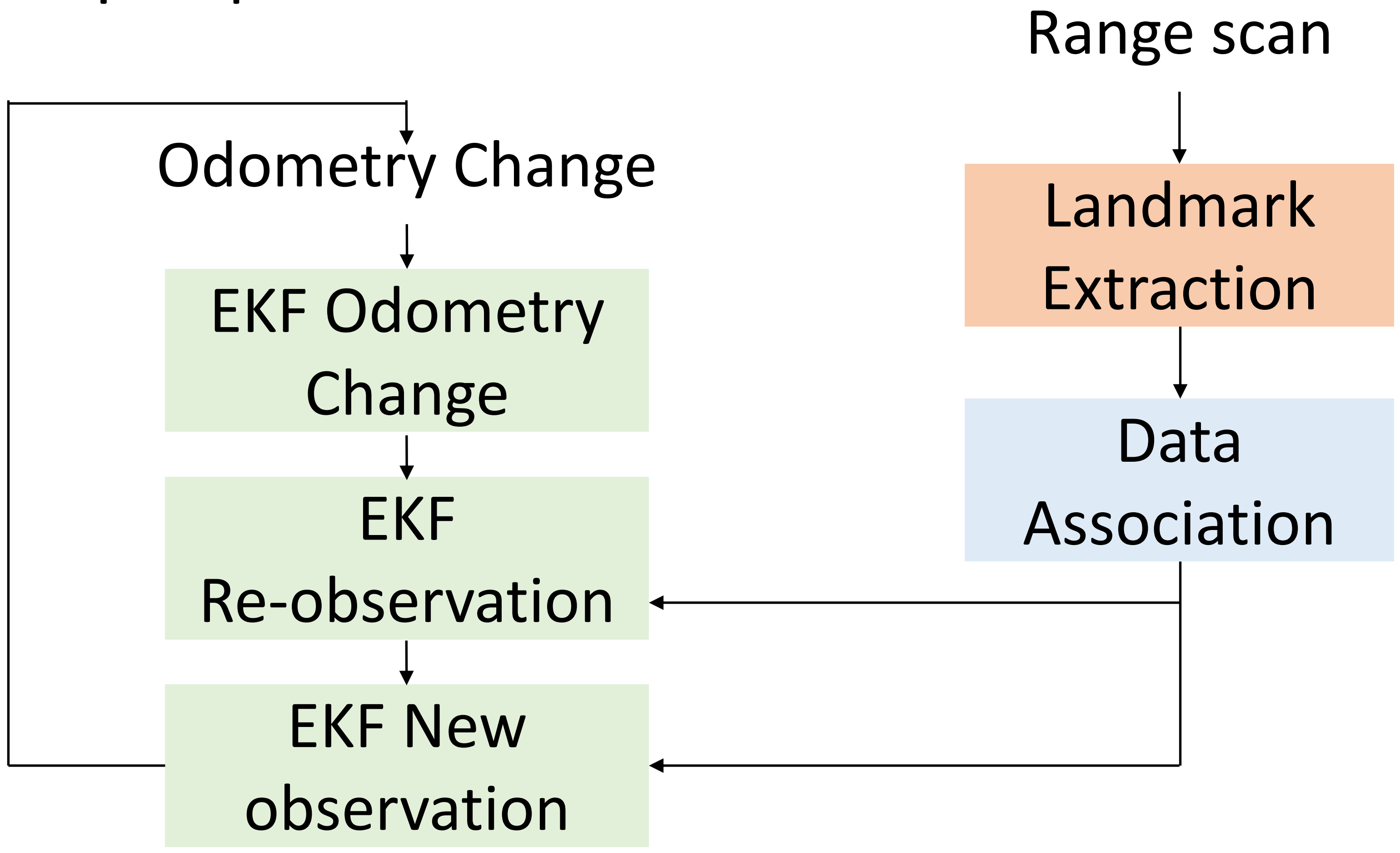
- Use **environment** to **update** position of robot
- Odometry can be erroneous
- Use range measurement devices to correct position
  - Extract features from environment
  - re-observing when robot moves around

EKF

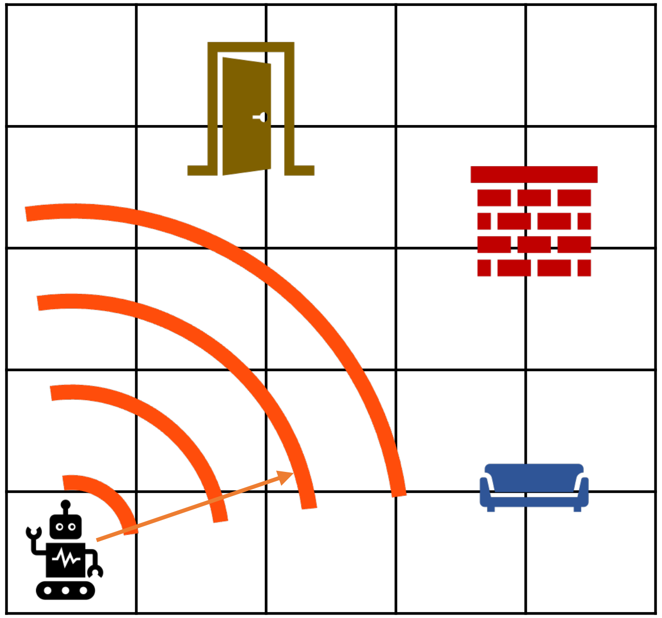
- "features" ➔ **landmarks**

EKF tracks **uncertainty** in position and landmarks

SLAM Steps | Outline

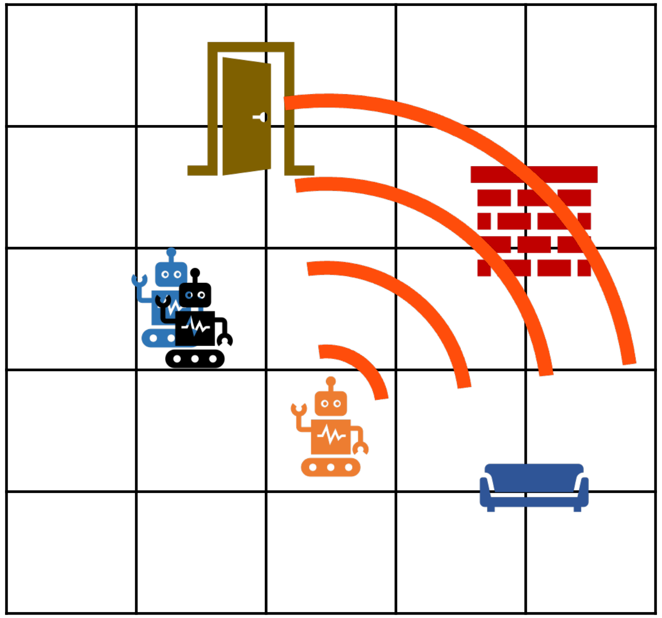


SLAM Steps | Abstract View



SLAM Steps | Abstract View

Robot trusts sensors more than odometry!



Mismatch in position!

SLAM | Data

LiDAR, RADAR, etc. provide data about surroundings

Odometry data provides **approximate** position of robot

Challenge ➔ **synchronizing** the timing of both

LiDAR has a higher rate than odometry

Solution ➔ **Extrapolate** the data

Easier to extrapolate odometry data

SLAM | Landmarks

- Features that can be **re-observed** and **distinguished from environment**
- Used by robot to find out where it is ➔ **localize** itself
- Types of landmarks depend on the environment

Landmarks should be:

- **Re-observable** and viewable from different angles & positions
- **Unique** enough to be identifiable between time steps
- **Plentiful** in the environment
- **Stationary**

SLAM | Indoor Landmarks

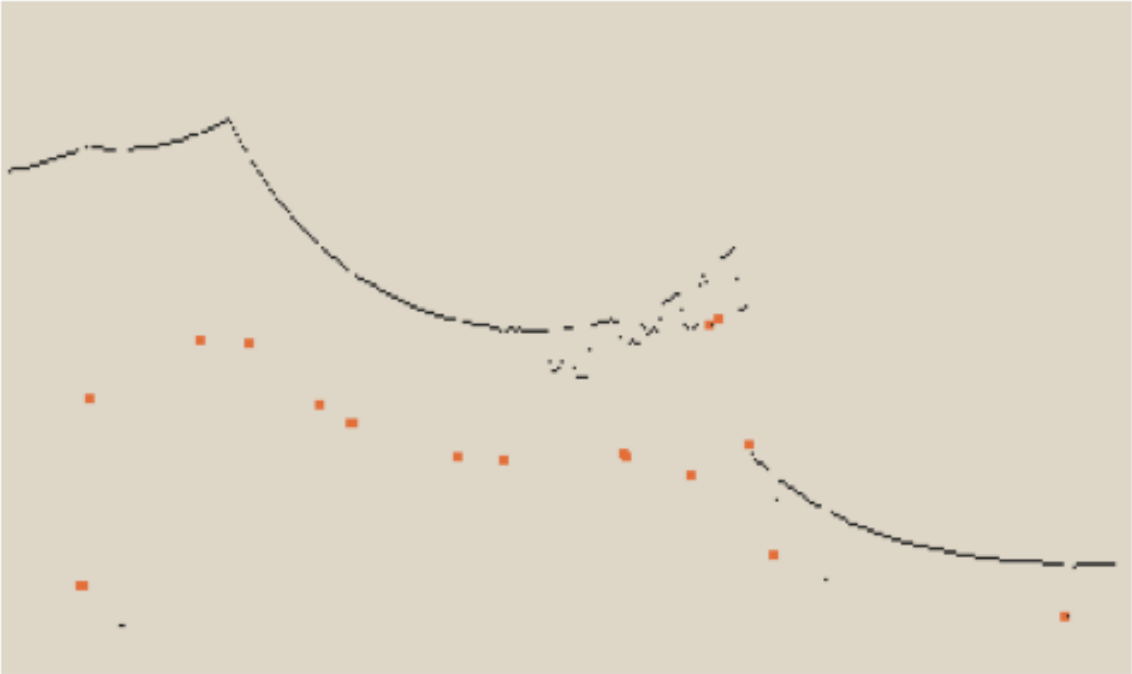
- Lots of straight lines
- Well defined corners

SLAM | Landmark Extraction

- Depends on type of landmarks
- Two landmark extraction algorithms
  - Spikes
  - RANSAC

SLAM | Landmark Extraction | Spikes

- Uses **extrema** to find landmarks
- **two values differ > certain amount** [e.g. 0.5]
- Detects big changes
  - Some beams reflect from walls, others don’t



SLAM | Landmark Extraction | RANSAC

- RANdom SAmpling Consensus
- Extract lines from a laser scan
  - (e.g. straight lines from walls)
- Lines used as landmarks

SLAM | RANSAC | High-Level

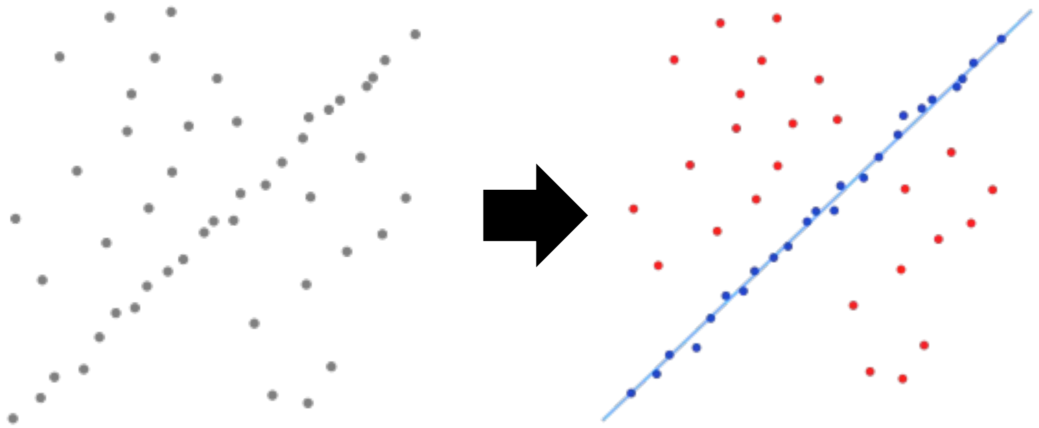
Random sampling of laser reading

Least square approximation ➔ best line through readings

SLAM | RANSAC | High-Level

Random sampling of laser reading

Least square approximation ➔ best line through readings

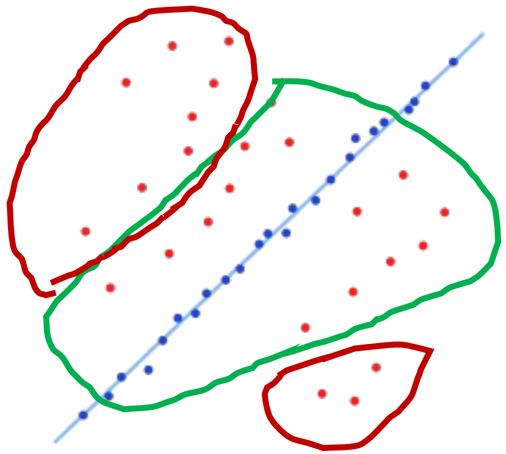


SLAM | RANSAC | High-Level

Random sampling of laser reading

Least square approximation ➔ best line through readings

How many laser readings lie close to best fit line?



SLAM | RANSAC | High-Level

Random sampling of laser reading

Least square approximation ➔ best line through readings

How many laser readings lie close to best fit line?

If number > threshold ➔ line is seen

Consensus

SLAM | RANSAC | Algorithm

While

- there are still unassociated laser readings
- # of readings > consensus **C**
- completed < **N** trials

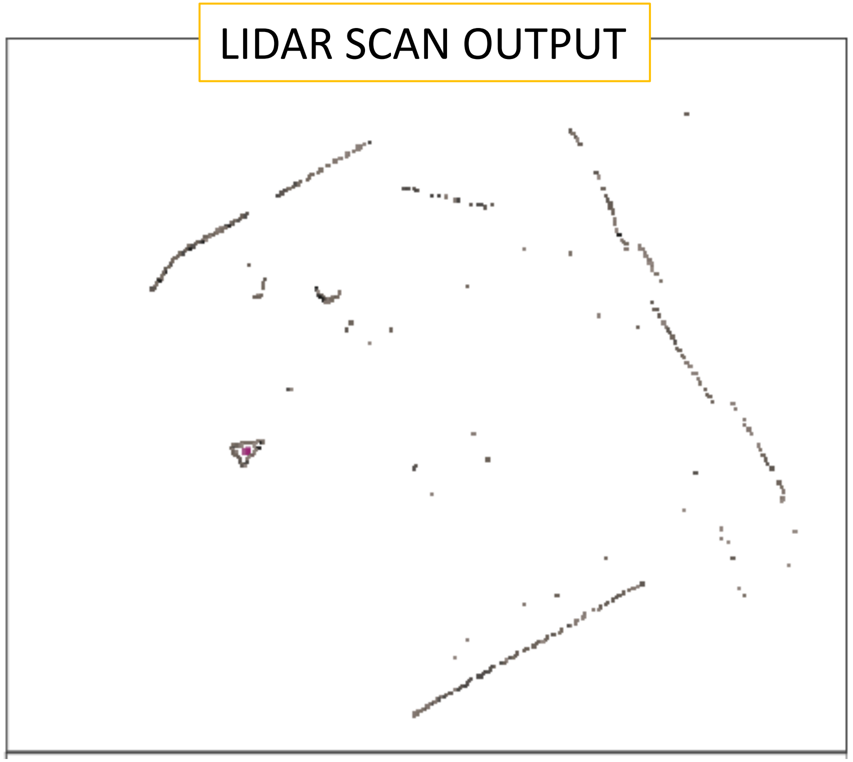
N→ max number of attempts
S → number of samples to compute initial line
D → degrees from initial reading to sample from
X → max distance reading may be from line
C → number of points that must line on line

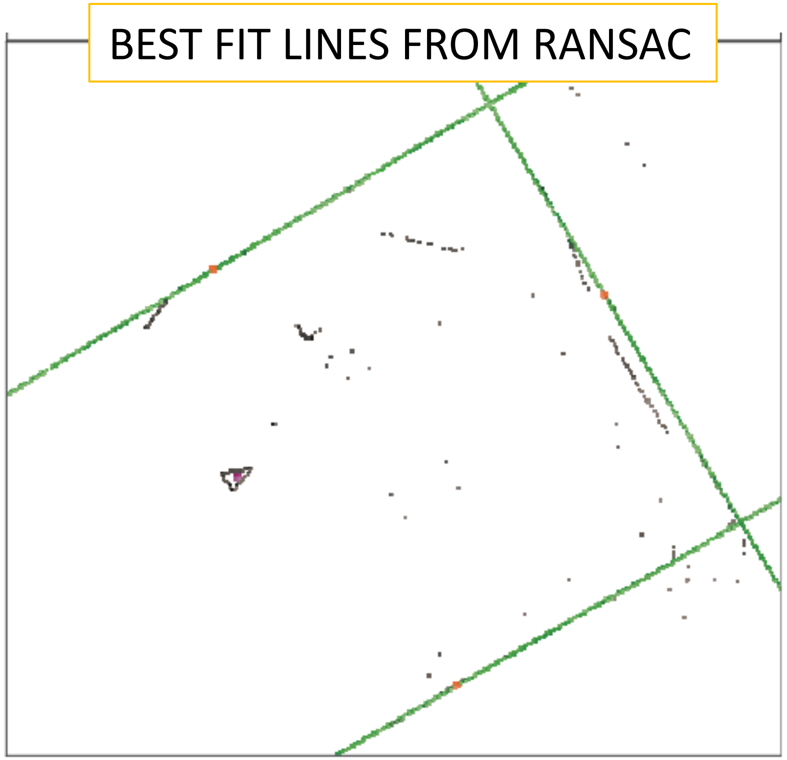
Do

- select *random laser data reading*, **R**
- randomly sample **S** data readings within **D** degrees of **R**
- calculate *least squares best fit line* using S and R
- determine how many laser data readings lie within **X** cm of best fit line
- if number of laser data readings on best fit line > *consensus* **C**
  - calculate *new least squares best fit line* ➔ based on all readings that lie on old line
  - add new best fit line to lines extracted so far
  - remove number of readings lying on this line from total set of unassociated readings

SLAM | RANSAC | Example

- Can extrapolate lines as dots as well → easier calculations
- RANSAC is **robust against people**





SLAM | Spikes vs RANSAC

Spikes	**RANSAC**
Simple algorithm	More involved calculations
Not robust against people	Robust against people

SLAM | Data Association

- **Matching** observed landmarks from different scans with each other
- **Re-observing** landmarks

SLAM | Data Association | Challenges

- May not re-observe landmarks at every step
- May wrongly observe something as landmark
  - never seen again!
- Wrong associate a landmark to a previously seen one

SLAM Data Association Policy

- Assume a **database** of previously seen landmarks
  - Initially empty
- Don't consider a landmark unless seen **N** times

Nearest Neighbor Approach

- use landmark extraction to extract all visible landmarks
- associate each extracted landmark → closest landmark seen > **N** times in database
- pass each pair of associations (extracted, seen in database) through validation gate
  - If pair passes validation date, it must be same landmark → increment number in database
  - if pair fails validation gate → add as new landmark in database

Validation Gate → check if landmark lies within area of uncertainty from EKF

SLAM Challenges

- Localization errors accumulate over time
  - E.g. in a loop, robot's start/end positions don't match
- Localization fails and map position is lost
  - Discontinuities in position estimates
- High computational costs
  - image processing/point clouds/etc.

➔pose graphs

➔EKF+landmarks

➔Parallelism

References

- SLAM for Dummies:

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- SLAM Overview [Matlab article]

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- SLAM examples and Matlkab code/API form

https://www.mathworks.com/help/nav/slam.html

- SLAM using pose graph estimation:
- https://www.youtube.com/watch?v=saVZtgPyyJQ&list=PLn8PRpmsu08rLRGrnF-S6TyGrmcA2X7kg&index=3