ShanghaiTech University
上海科技大学
School of Information Science and Technology
信息科学与技术学院

Mobile Robotics

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Lecture 7

PAPER PRESENTATION

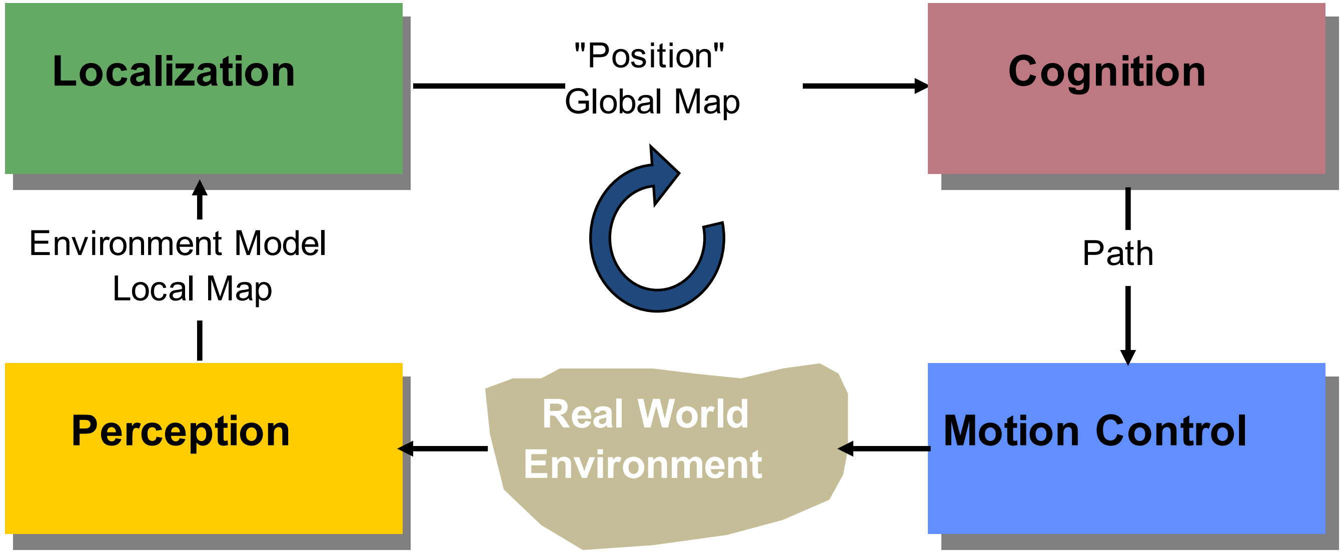
Presentation

- Submit pdf or ppt Monday, Dec 28st , 10pm
- Presentation on Tuesday, Dec 29nd
- 10 minute presentation plus 5 minutes questions
  - Do not rush your presentation! Better present less items more slowly!
  - 10 minute presentation => 5 – max. 10 slides
  - Maybe have a slide at towards the end that you can skip if you run out of time.
  - Give a test presentation to your friends beforehand!
- Finish preparing your slides early (e.g. Dec 24th), such that you have time practicing and improving the slides – but do NOT learn your presentation by heart!
- Send you presentation latest Dec 25th to me and I will give you feedback before your final presentation!
- Topic: any full paper (min 6 pages) of ICRA 2015: http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=7128761

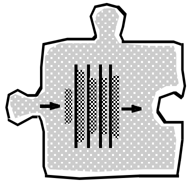
Scoring of the Presentation

- 10 %: Your basic understanding/ knowledge about the paper you present
- 20 %: Presentation timing (plus or minus one minute is ok) – no rushing – good speed!
- 10 %: Correct written English in presentation:
  - No complete sentences, no grammatical or spelling mistakes
- 10 %: Good structure of presentation:
  - Depends on the type of paper, how much time you have, how long you need to present the main achievement.
  - For example: outline, introduction/ motivation, **problem statement**, state of the art, **approach**, experiments, **results**, **conclusion**, outlook
- 20 %: Clarity of written presentation
- 10 %: Good presentation style:
  - Interact with audience: look at the whole room (not just your slides, notes, or the back of the room)
  - Present the paper – do not read (or repeat the learned) speech from a prepared text
  - Use the presentation as visual aid – not as your tele-prompter to read from
  - Move your body – do not stand frozen at one place
- 10 %: Answering the questions
  - Questions have to be asked and answered in English – Chinese can be used for clarification
- 10 %: Asking questions to other students!
- **Not** scored: Your English skill

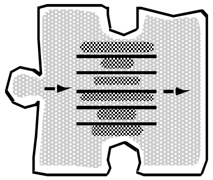
Control Architectures / Strategies



- Two Approaches
  - Classical AI
    - complete modeling
    - function based
    - horizontal decomposition



  - New AI (Nouvelle AI)
    - sparse or no modeling
    - behavior based
    - vertical decomposition
    - bottom up

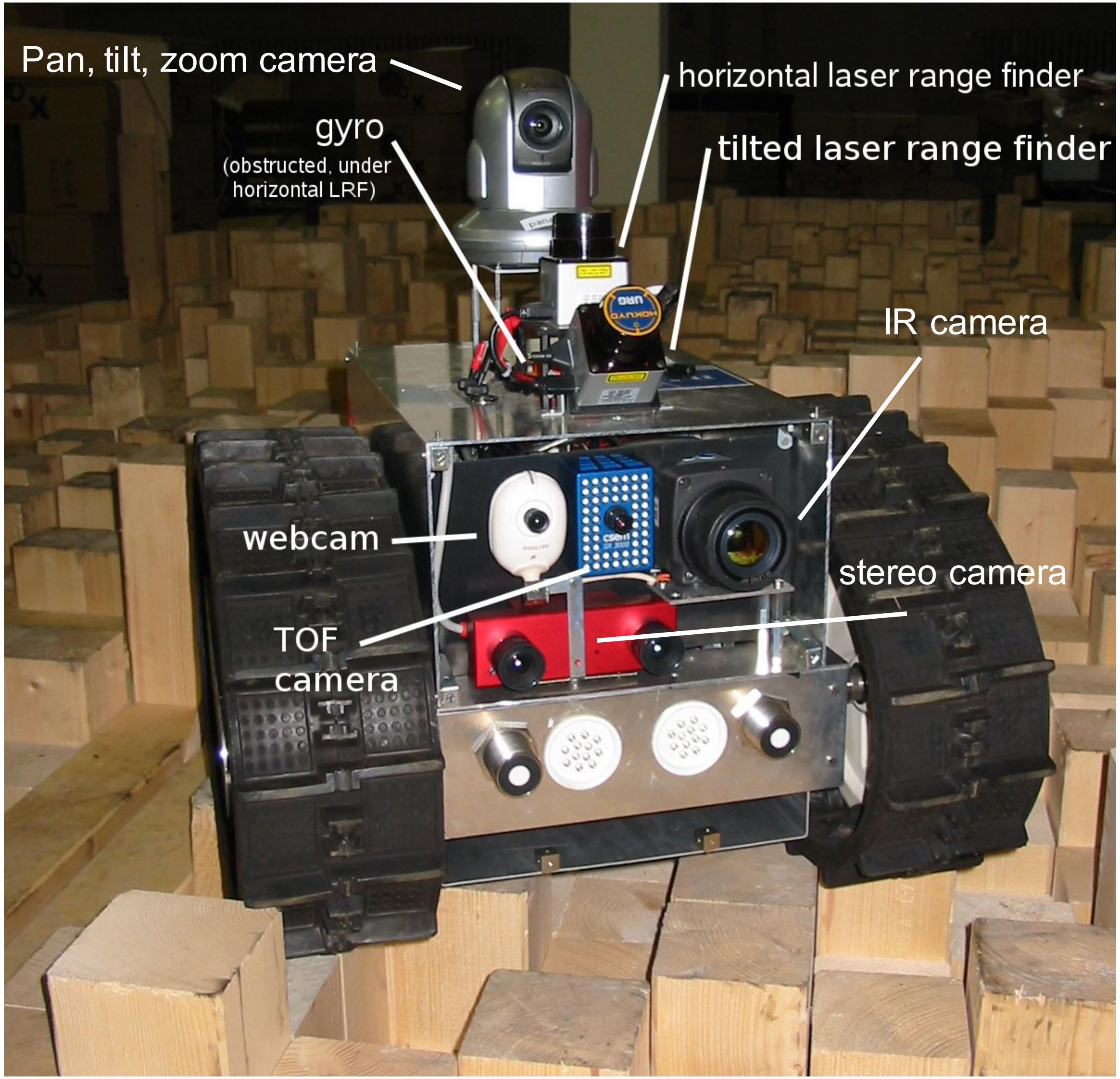


Classification of Sensors

- What:
  - Proprioceptive sensors
    - measure values internally to the system (robot),
    - e.g. motor speed, wheel load, heading of the robot, battery status
  - Exteroceptive sensors
    - information from the robots environment
    - distances to objects, intensity of the ambient light, unique features.
- How:
  - Passive sensors
    - Measure energy coming from the environment
  - Active sensors
    - emit their proper energy and measure the reaction
    - better performance, but some influence on environment

Sensors: outline

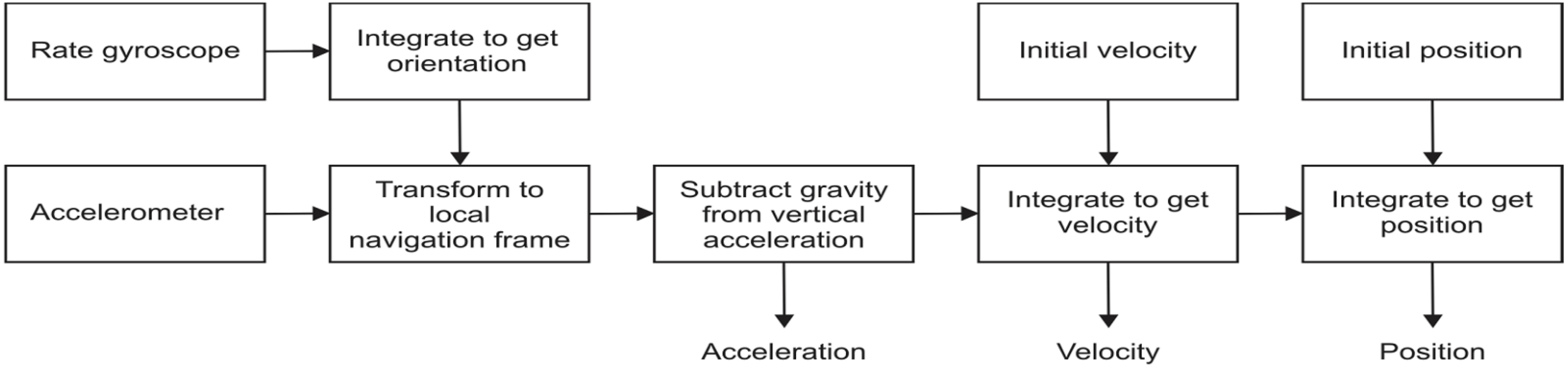
- Optical encoders
- Heading sensors
  - Compass
  - Gyroscopes
- Accelerometer
- IMU
- GPS
- Range sensors
  - Sonar
  - Laser
  - Structured light
- Vision



Inertial Measurement Unit (IMU)

- Device combining different measurement systems:
  - Gyroscopes, Accelerometers, Compass
- Estimate relative position (x, y, z), orientation (roll, pitch, yaw), velocity, and acceleration
- Gravity vector is subtracted to estimate motion
  - Initial velocity has to be known

Xsens MTI



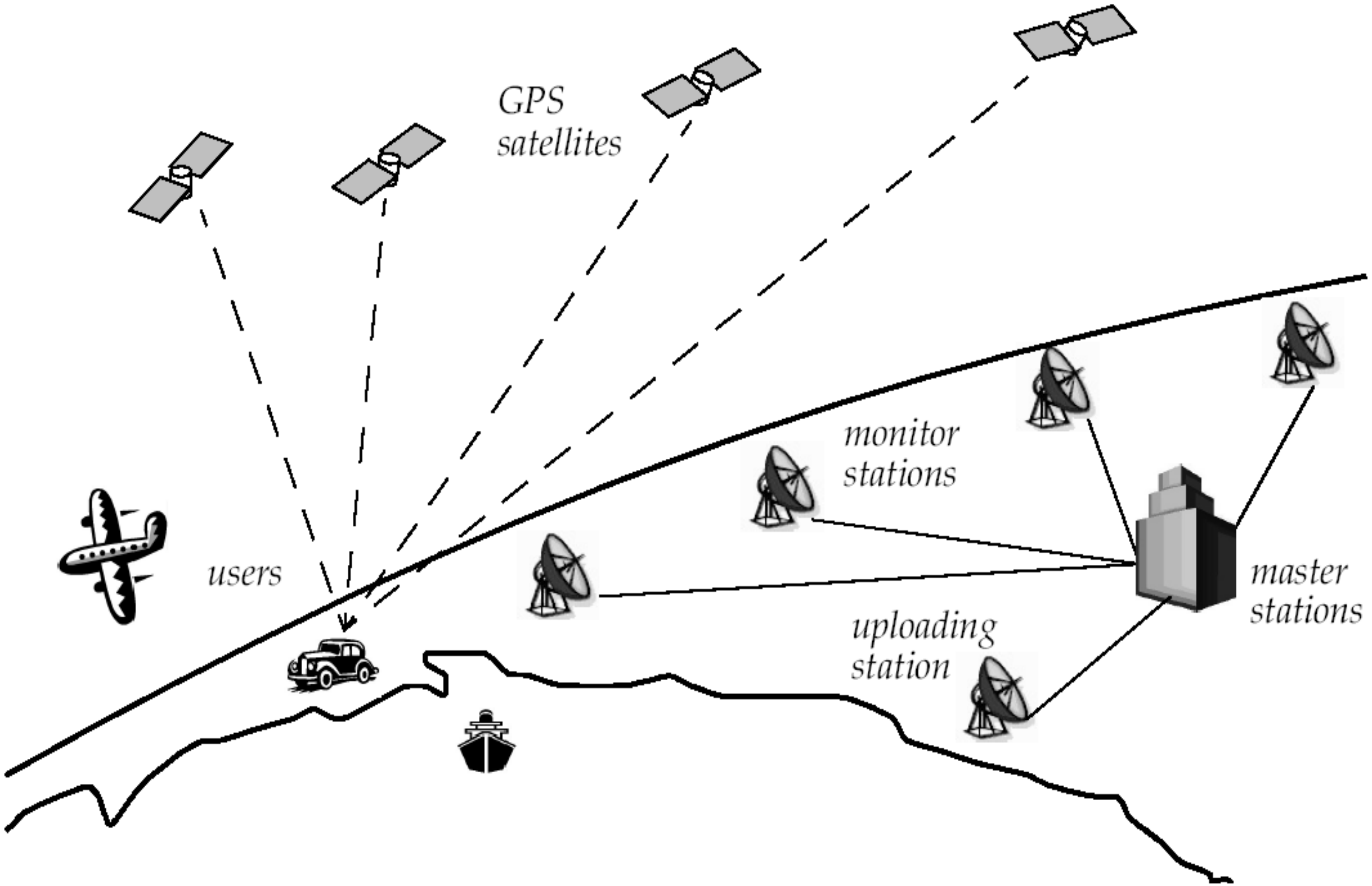
IMU Error and Drift

- Extremely sensitive to measurement errors in gyroscopes and accelerometers:
  - drift in the gyroscope unavoidably =>
  - error in orientation relative to gravity =>
  - incorrect cancellation of the gravity vector.

- Accelerometer data is integrated twice to obtain the position => gravity vector error leads to quadratic error in position.

- All IMUs drift after some time
  - Use of external reference for correction:
  - compass, GPS, cameras, localization

Global Positioning System (GPS) (2)



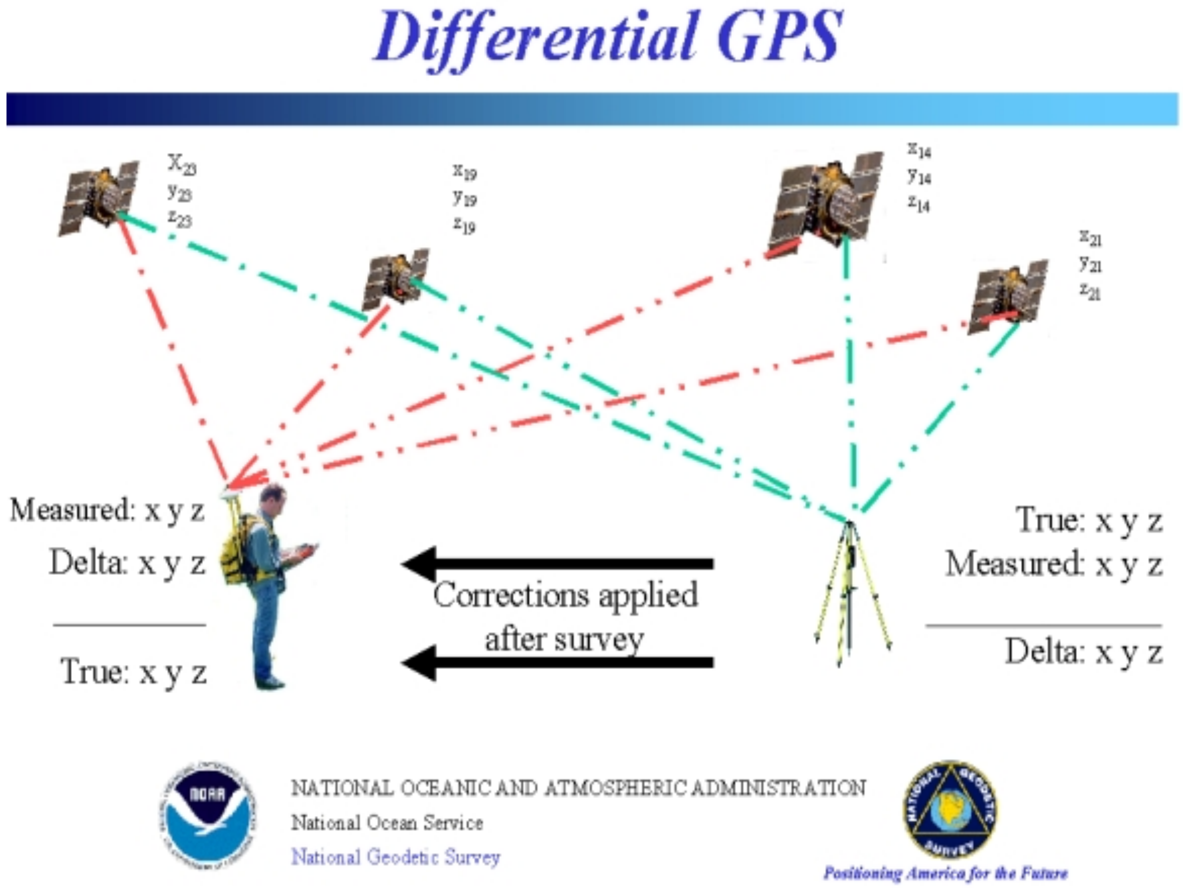
GPS Error Sources

Satellite clock errors uncorrected by monitor stations may result in one meter errors:

- Ephemeris data errors: 1 meter
- Tropospheric delays: 1 meter.
  - The troposphere is the lower part (ground level to from 8 to 13 km) of the atmosphere that experiences the changes in temperature, pressure, and humidity associated with weather changes. Complex models of tropospheric delay require estimates or measurements of these parameters.
- Unmodeled ionosphere delays: 10 meters.
  - The ionosphere is the layer of the atmosphere from 50 to 500 km that consists of ionized air. The transmitted model can only remove about half of the possible 70 ns of delay leaving a ten meter un-modeled residual.
- Number of satellites under line of sight

Differential Global Positioning System (dGPS)

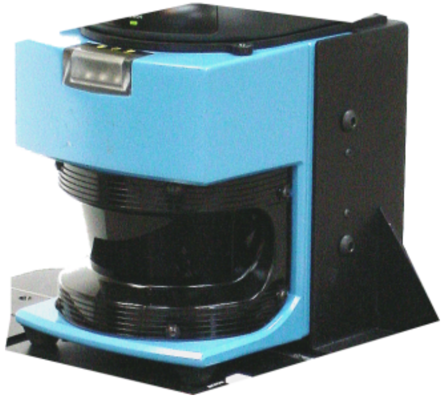
- Base station GPS receiver: set up on a precisely known location
- Base station receiver calculates its position based on satellite signals
- Compares this location to the known location
- Difference is applied to the GPS data recorded by the mobile GPS receivers
- Position accuracies in sub-meter to cm range



Range sensors

- Sonar -->

- Laser range finder --->



- Time of Flight Camera --->

- Structured light ---------->

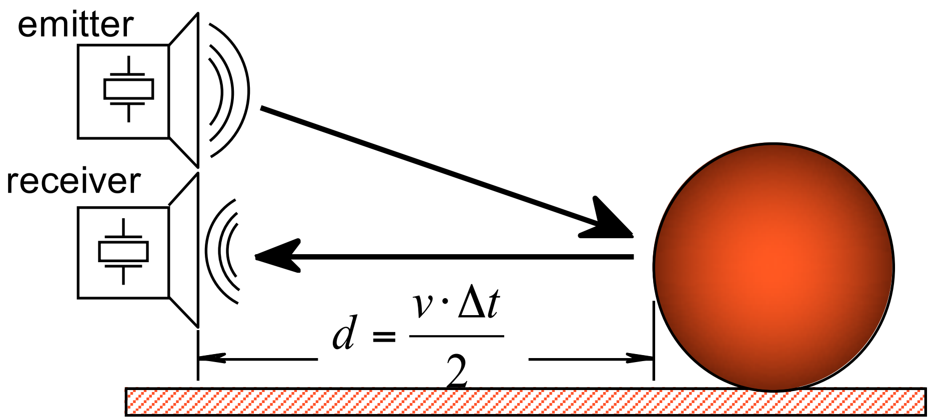
Range Sensors (time of flight) (2)

- It is important to point out
  - Propagation speed v of sound in air: 0.3 m/ms - 300 m/s
  - Propagation speed v of sound in water: 1.5 m/ms - 1,500 m/s

  - Propagation speed v of of electromagnetic signals: 0.3 m/ns,
    - one million times faster.
  - 3 meters
    - is 10 ms for an ultrasonic system
    - only 10 ns for a laser range sensor
    - time of flight with electromagnetic signals is not an easy task
    - laser range sensors expensive and delicate

- The quality of time of flight range sensors mainly depends on:
  - Inaccuracies in the time of fight measure (laser range sensors)
  - Opening angle of transmitted beam (especially ultrasonic range sensors)
  - Interaction with the target (surface, specular reflections)
  - Variation of propagation speed (sound)
  - Speed of mobile robot and target (if not at stand still)

Factsheet: Ultrasonic Range Sensor (1)



speed of sound in air approx.: 0.3 m/ms - 300 m/s

1. Operational Principle

An ultrasonic pulse is generated by a piezo-electric emitter, reflected by an object in its path, and sensed by a piezo-electric receiver. Based on the speed of sound in air and the elapsed time from emission to reception, the distance between the sensor and the object is easily calculated.

2. Main Characteristics

- Precision influenced by angle to object (as illustrated on the next slide)
- Useful in ranges from several cm to several meters
- Typically relatively inexpensive

3. Applications

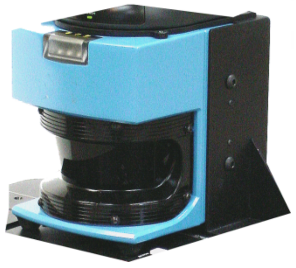
- Distance measurement (also for transparent surfaces)
- Collision detection

Ultrasonic Sensor (time of flight, sound) (4)

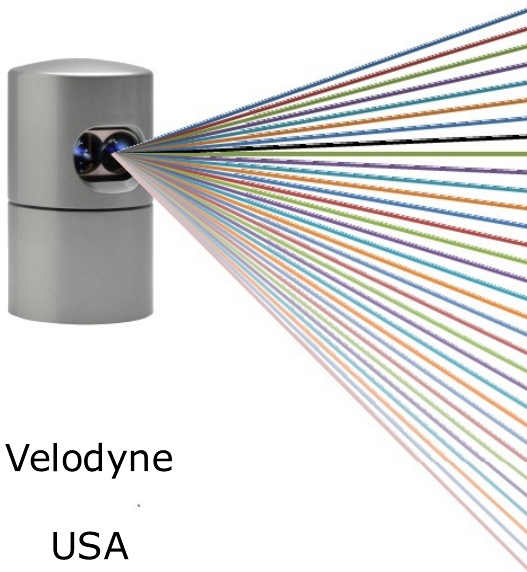
- Bandwidth
  - measuring the distance to an object that is 3 m away will take such a sensor 20 ms, limiting its operating speed to 50 Hz. But if the robot has a ring of 20 ultrasonic sensors, each firing sequentially and measuring to minimize interference between the sensors, then the ring's cycle time becomes 0.4 seconds => frequency of each one sensor = 2.5 Hz.
  - This update rate can have a measurable impact on the maximum speed possible while still sensing and avoiding obstacles safely.

Laser Range Sensor (time of flight, electromagnetic) (1)

- Is called Laser range finder or Lidar (LIght Detection And Ranging)





SICK

Germany

High Quality,
Safety Certification
Expensive

Hokuyo

Japan

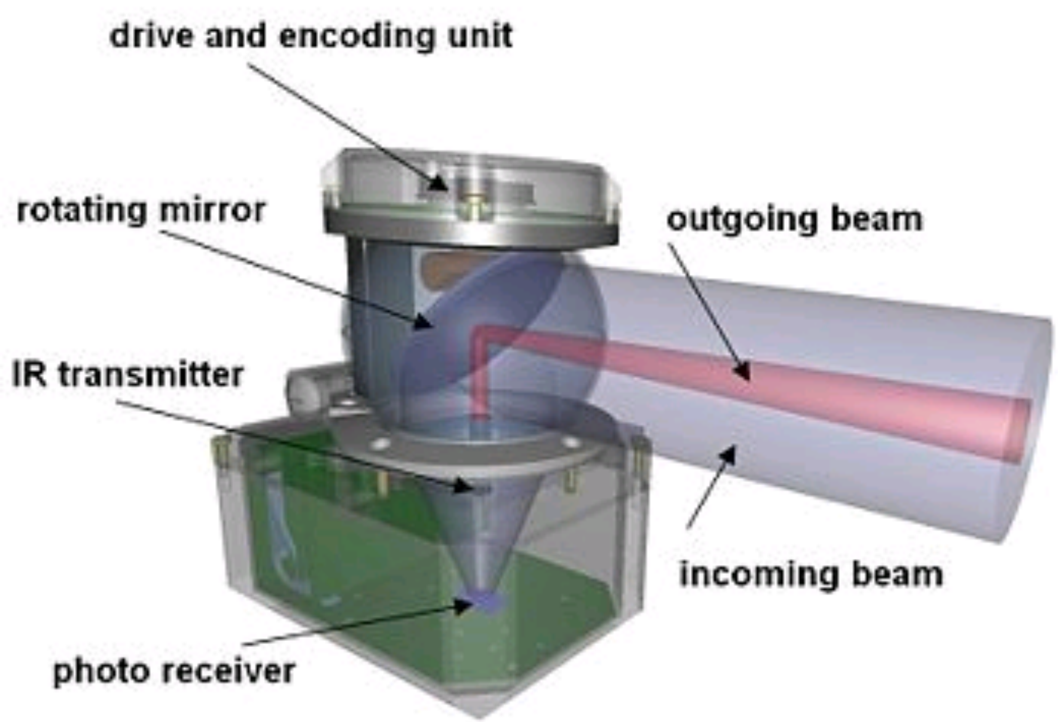
Small sizes,
Popular for Robotics

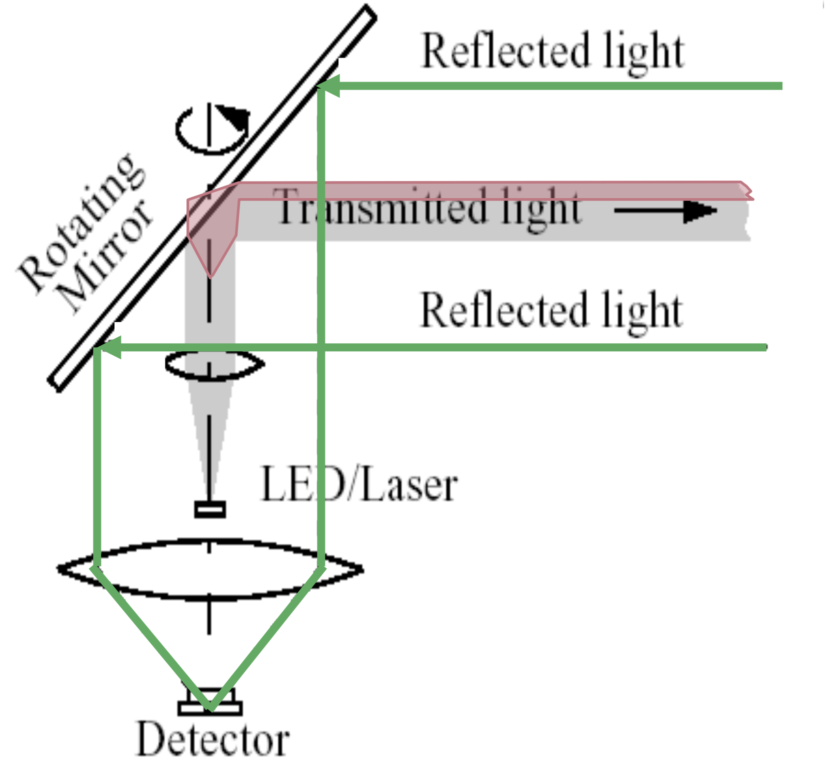
Velodyne

USA

3D Sensor (32 beams),
For autonomous cars,
Extremely Expensive

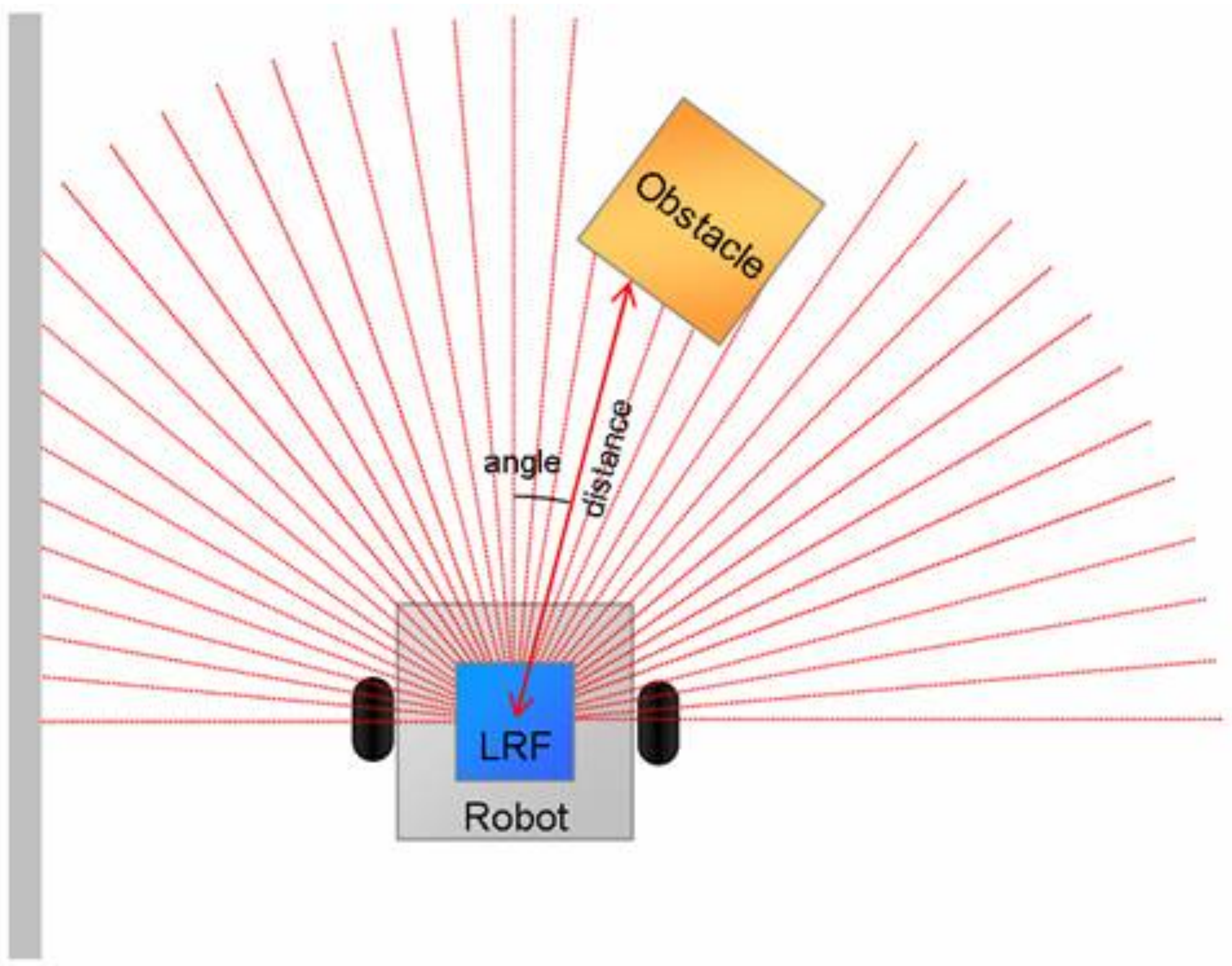
Laser Range Sensor (aka LIDAR)

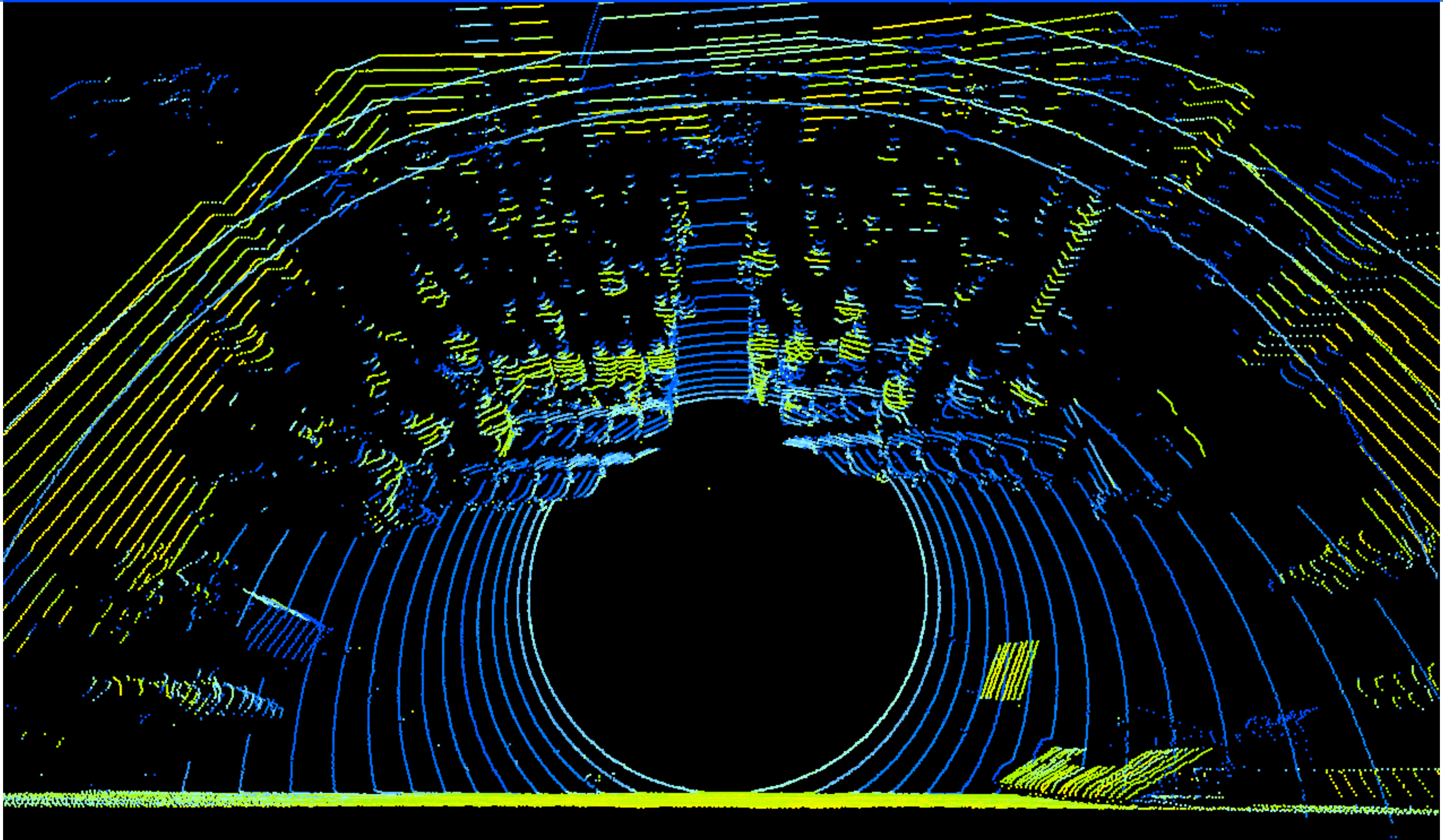




- Transmitted and received beams coaxial
- Transmitter illuminates a target with a collimated laser beam
- Received detects the time needed for round-trip
- A mechanical mechanism with a mirror sweeps
  - 2D or 3D measurement

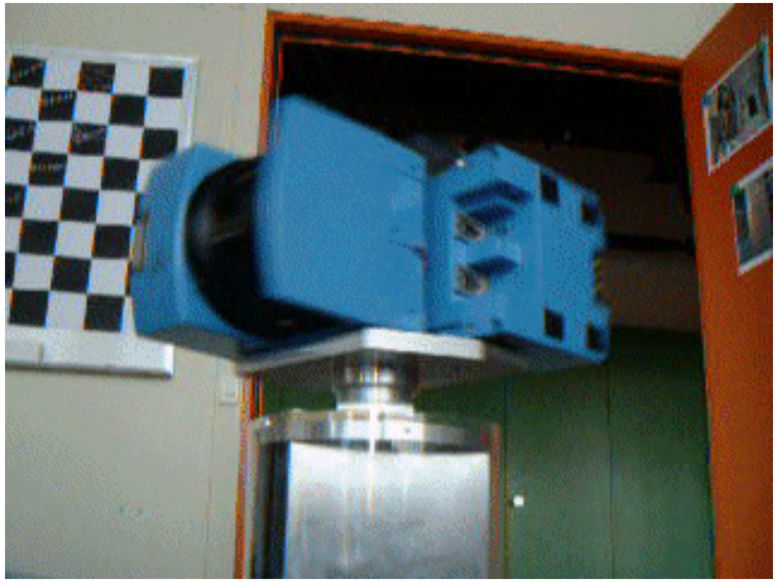
2D Laser Range Finder Scan





3D Laser Range Finder (LRF) (1)

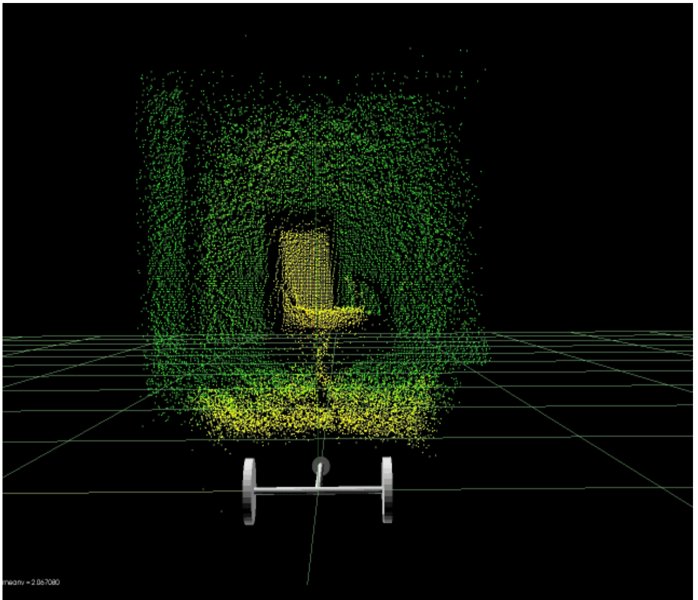
- A 3D laser range finder is a laser scanner that acquires scan data in more than a single plane.
- Custom-made 3D scanners are typically built by nodding or rotating a 2D scanner in a stepwise or continuous manner around an axis parallel to the scanning plane.
- By lowering the rotational speed of the turn-table, the angular resolution in the horizontal direction can be made as small as desired.
- A full spherical field of view can be covered (360° in azimuth and 90° in elevation).
- However, acquisition takes up to some seconds!



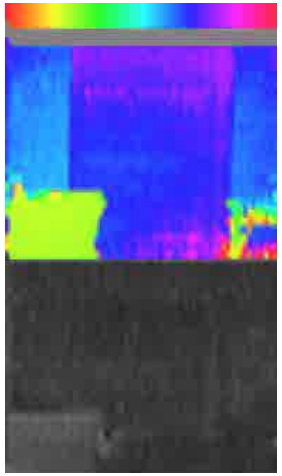
3D Range Sensor (4): Time Of Flight (TOF) camera

- A Time-of-Flight camera (TOF camera, figure) works similarly to a lidar with the advantage that the whole 3D scene is captured at the same time and that there are no moving parts. This device uses a modulated infrared lighting source to determine the distance for each pixel of a Photonic Mixer Device (PMD) sensor.

ZCAM
(from 3DV Systems now bought by Microsoft for Project Natal)



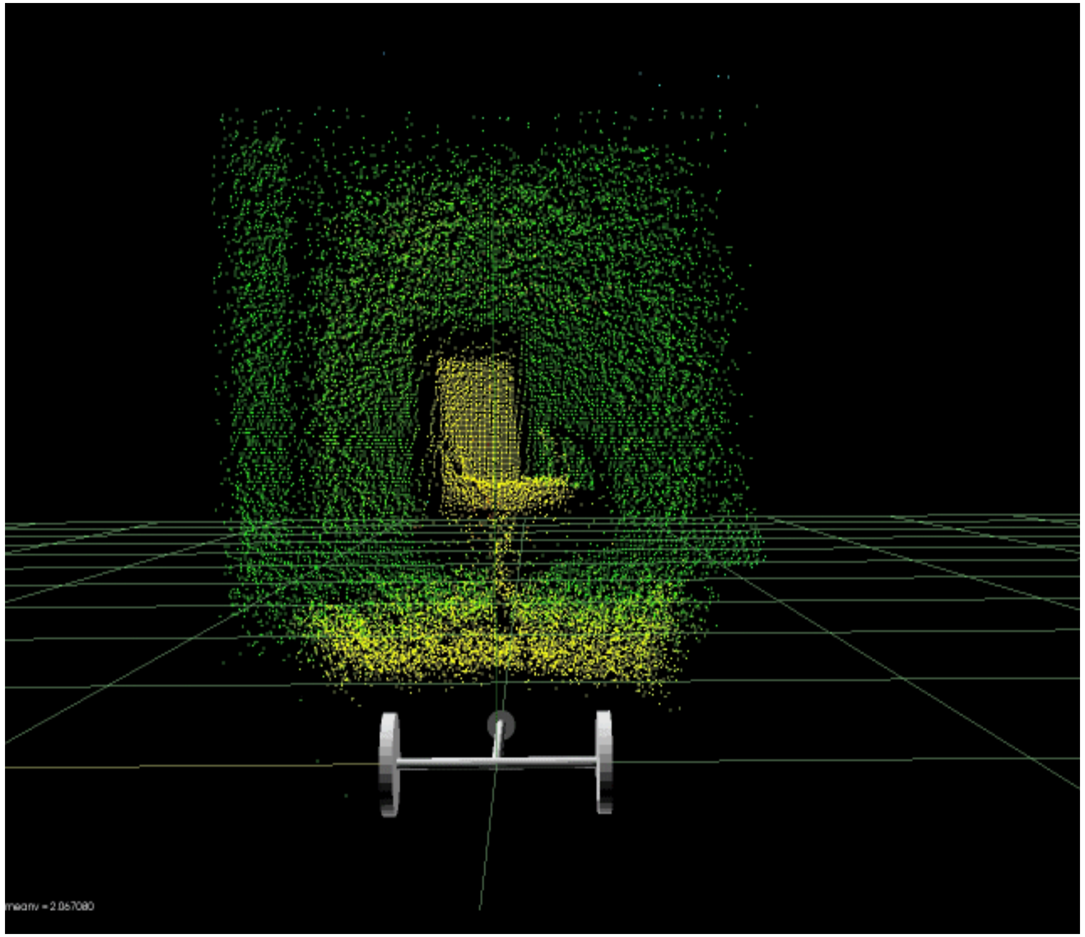
Swiss Ranger 3000
(produced by MESA)



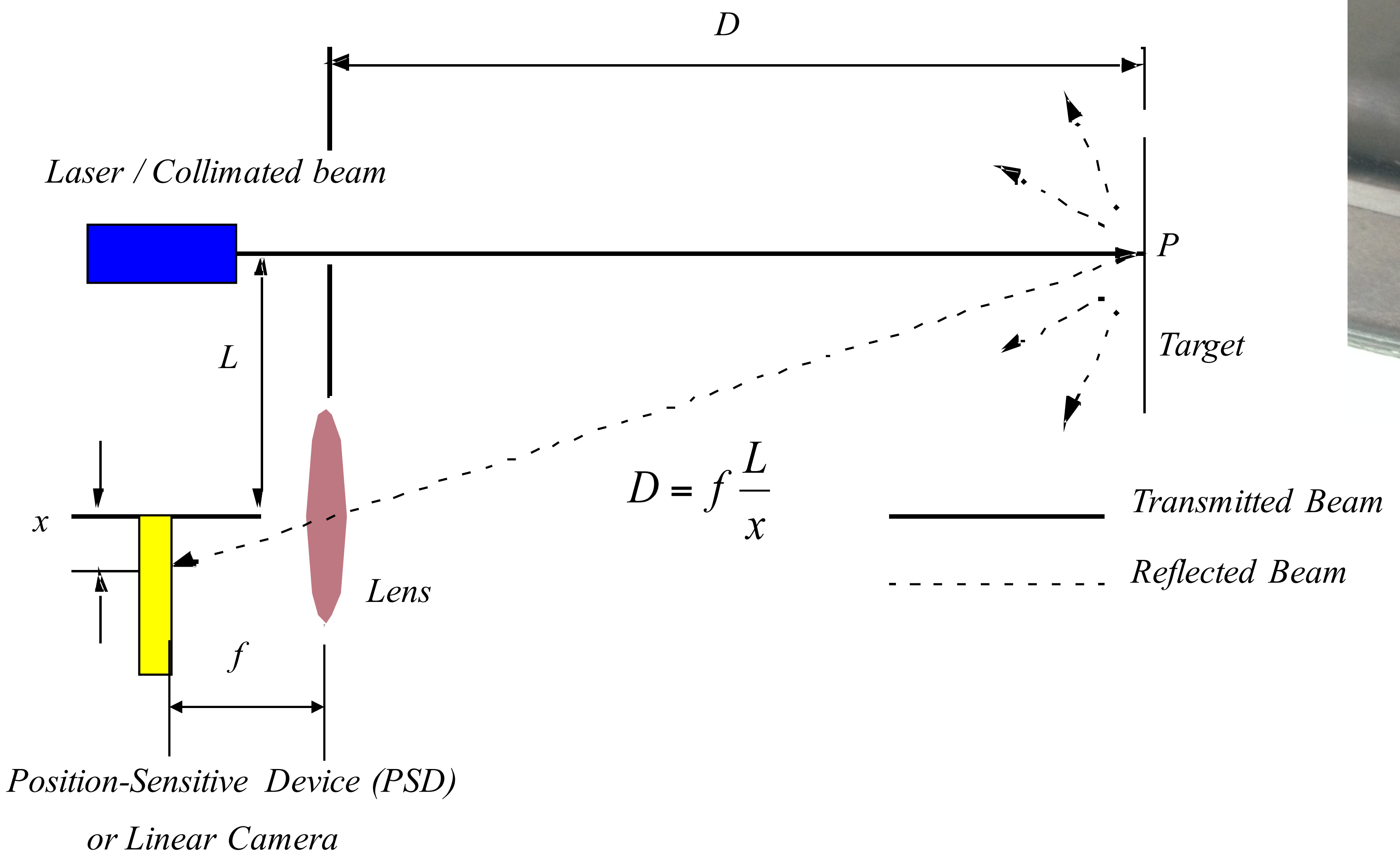
3D Range Sensor (4): Time Of Flight (TOF) camera

- Range Camera
  - 3D information with high data rate (100 Hz)
  - Compact and easy to manage
  - High, non-uniform measurement noise
  - High outlier rate at jump edges
  - However very low resolution (174x144 pixels)
  - ZCAM achieves 320x240 pixels

  - Sensitive to ambient infrared light!



Laser Triangulation (1D)

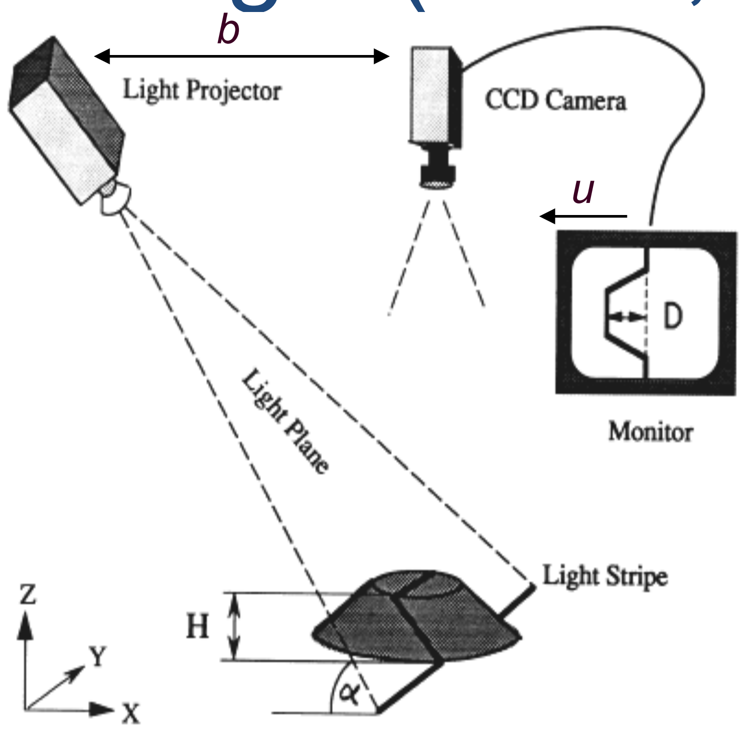


$$D = f\,\frac{L}{x}$$

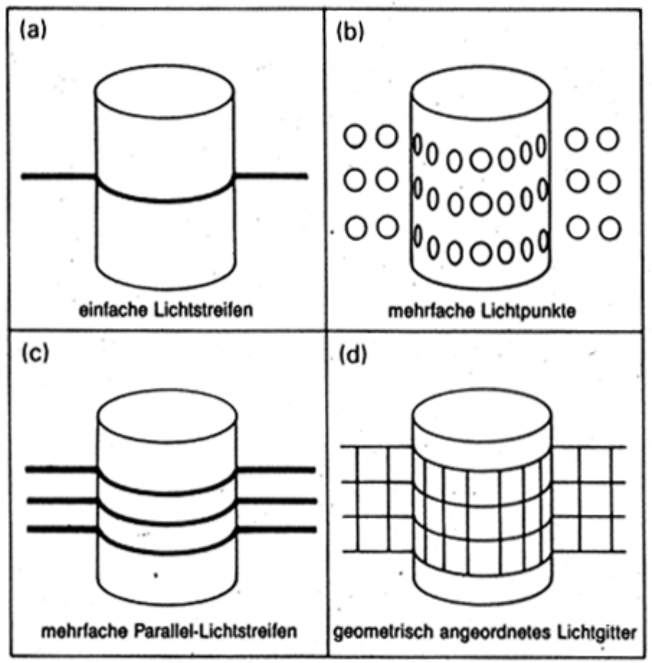
Cliff sensor on Turtle-bot

Structured Light (vision, 2 or 3D): Structured Light

a



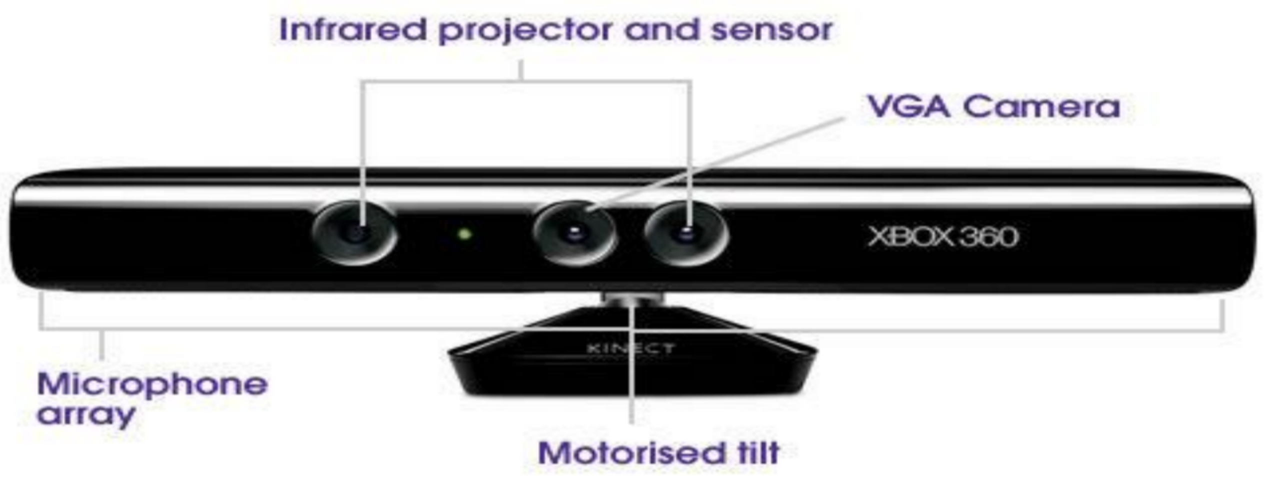
b



- Eliminate the correspondence problem by projecting structured light on the scene.
- Slits of light or emit collimated light (possibly laser) by means of a rotating mirror.
- Light perceived by camera
- Range to an illuminated point can then be determined from simple geometry.

RGB-D: PrimeSense Car

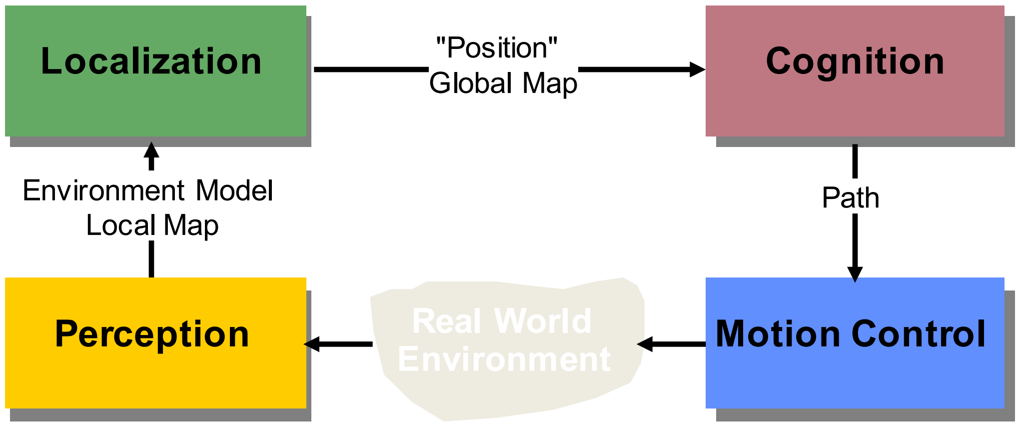
- Devices: Microsoft Kinect and Asus Xtion
- Developed by Israeli company PrimeSense in 2010



- Components:
  - IR camera (640 x 480 pixel)
  - IR Laser projector
  - RGB camera (640 x 480 or 1280 x 1024)
  - Field of View (FoV):
    - 57.5 degrees horizontally,
    - 43.5 degrees vertically

Depth Map

PERCEPTION



Sensors
Line extraction from laser scans
Uncertainties
Vision

Sildes from Roland Siegwart and Davide Scaramuzza, ETH Zurich

LINE EXTRACTION

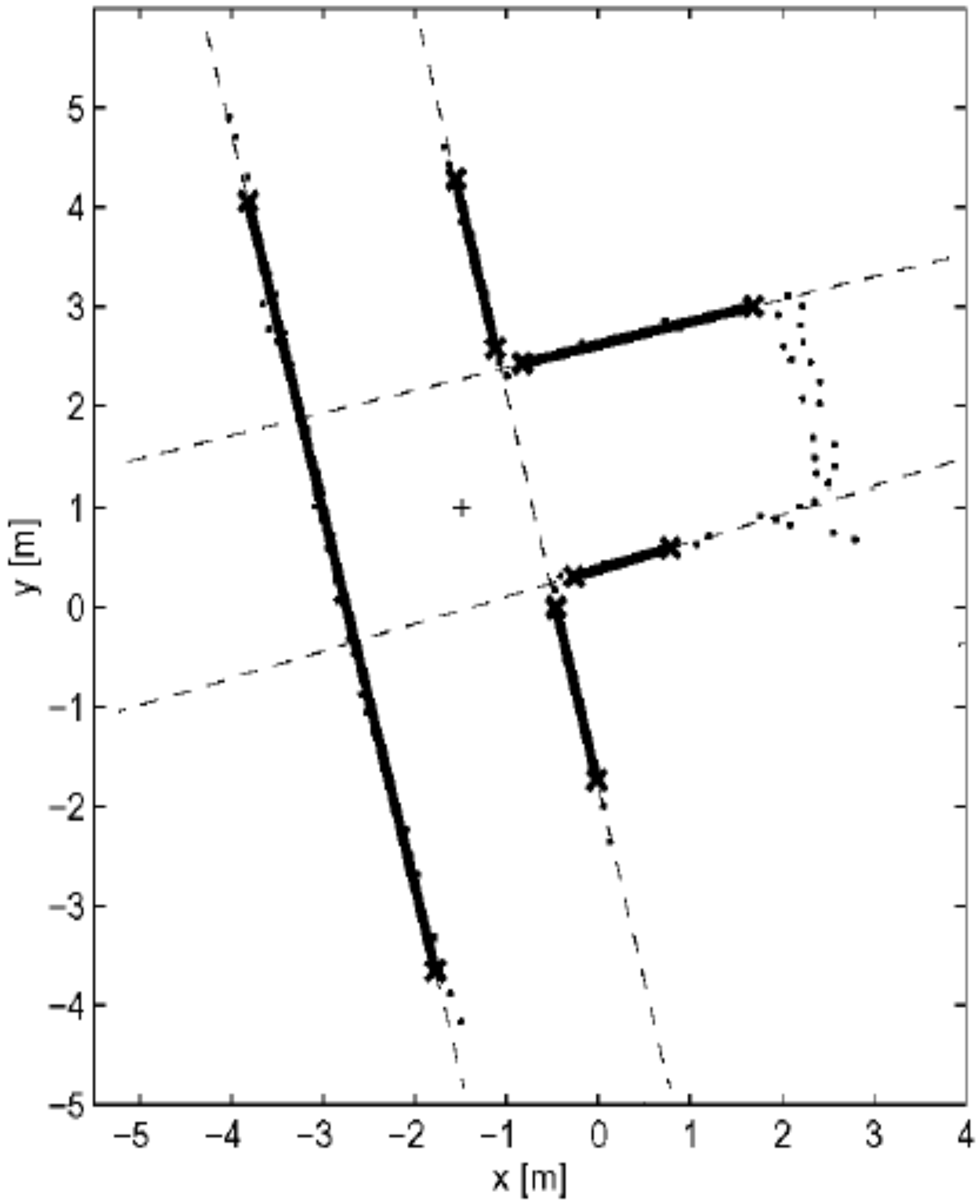
Split and merge
Linear regression
RANSAC
Hough-Transform

Line Extraction: Motivation

- Laser Range Scan
  - Example: 360 deg – black points
  - Example: dashed lines: desired line extractions

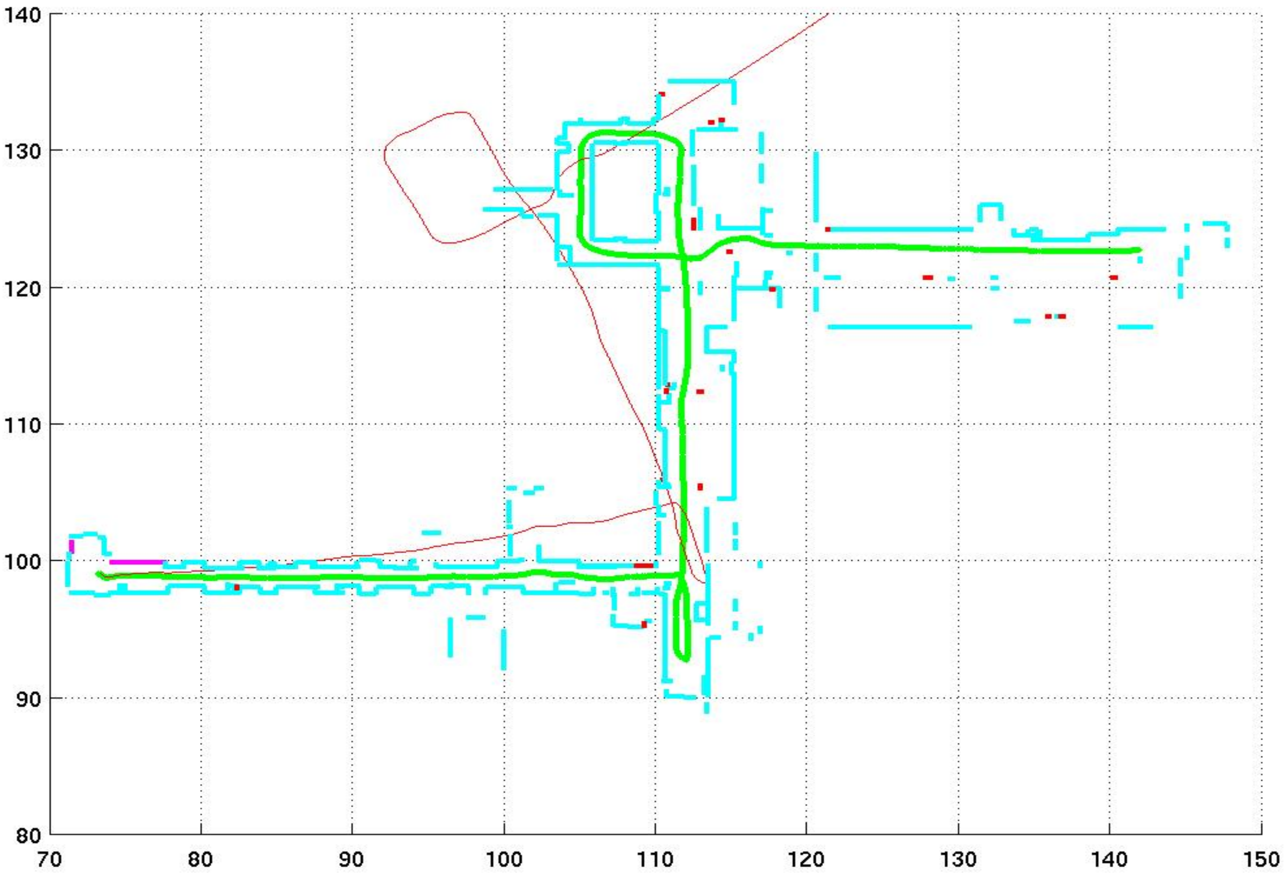
- Use detected lines for:
  - Scan registration (find out transform between frames of two consecutive LRF scans – change due to robot motion)

  OR
  - Mapping using line representation



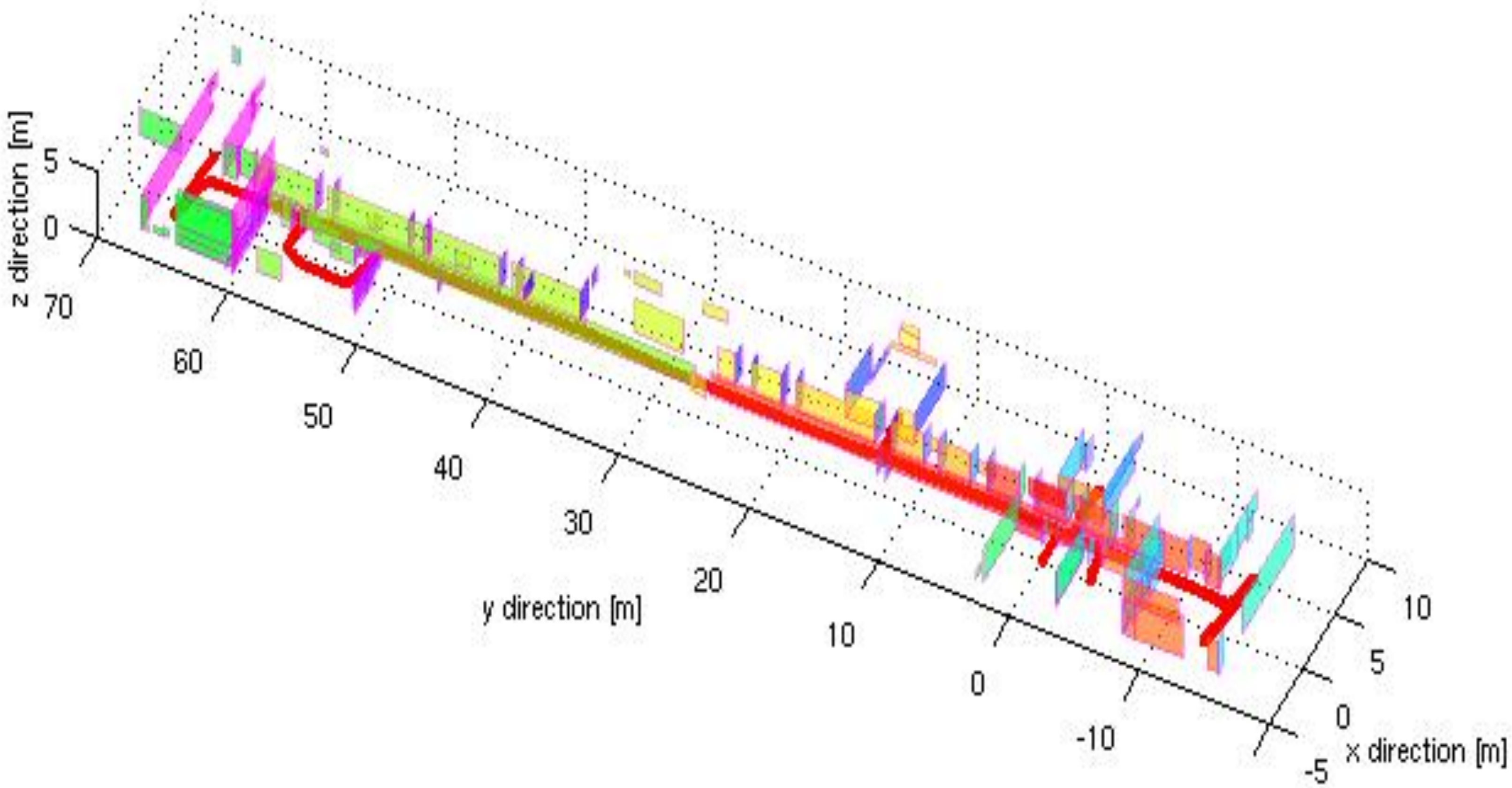
Line Extraction: Motivation

- Map of hallway built using line segments



Line Extraction: Motivation

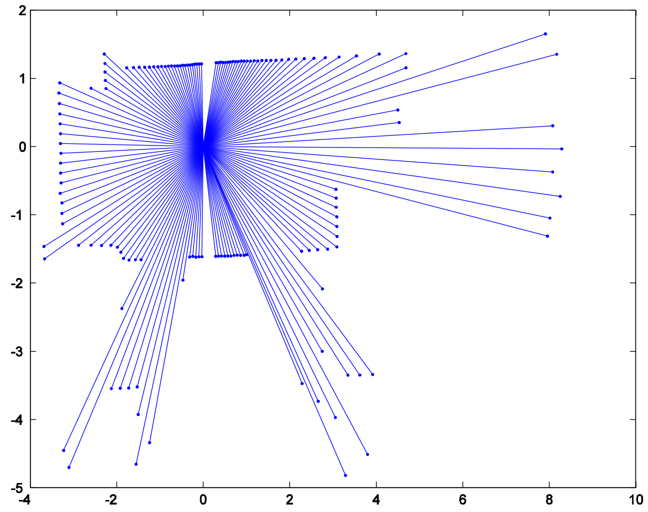
- Map of the hallway built using orthogonal planes constructed from line segments



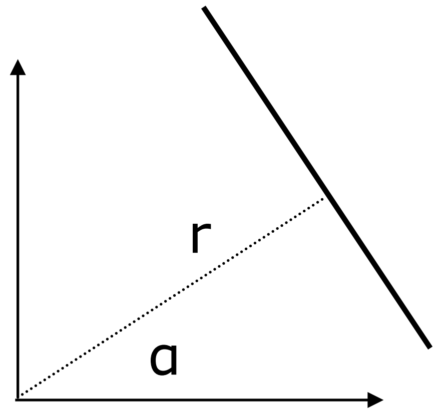
Line Extraction: Motivation

- Why laser scanner:
  - Dense and accurate range measurements
  - High sampling rate, high angular resolution
  - Good range distance and resolution.
- Why line segment:
  - The simplest geometric primitive
  - Compact, requires less storage
  - Provides rich and accurate information
  - Represents most office-like environment.

Line Extraction: The Problem



- Scan point in polar form: (ρ_i, θ_i)
- Assumptions:
  - Gaussian noise
  - Negligible angular uncertainty
- Line model in polar form:
  - $x \cos \alpha + y \sin \alpha = r$
  - $-\pi < \alpha <= \pi$
  - $r >= 0$



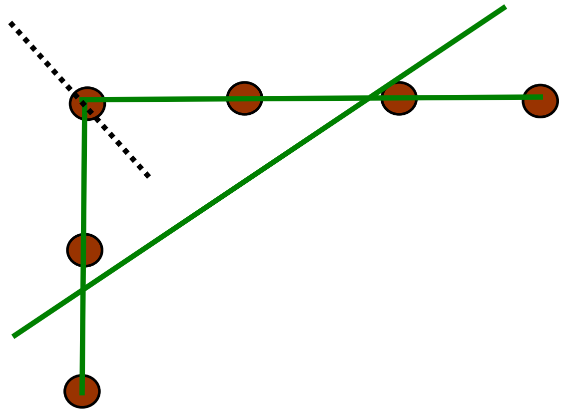
Line Extraction: The Problem (2)

- Three main problems:
  - How many lines ?
  - Which points belong to which line ?
    - This problem is called SEGMENTATION
  - Given points that belong to a line, how to estimate the line parameters ?
    - This problem is called LINE FITTING

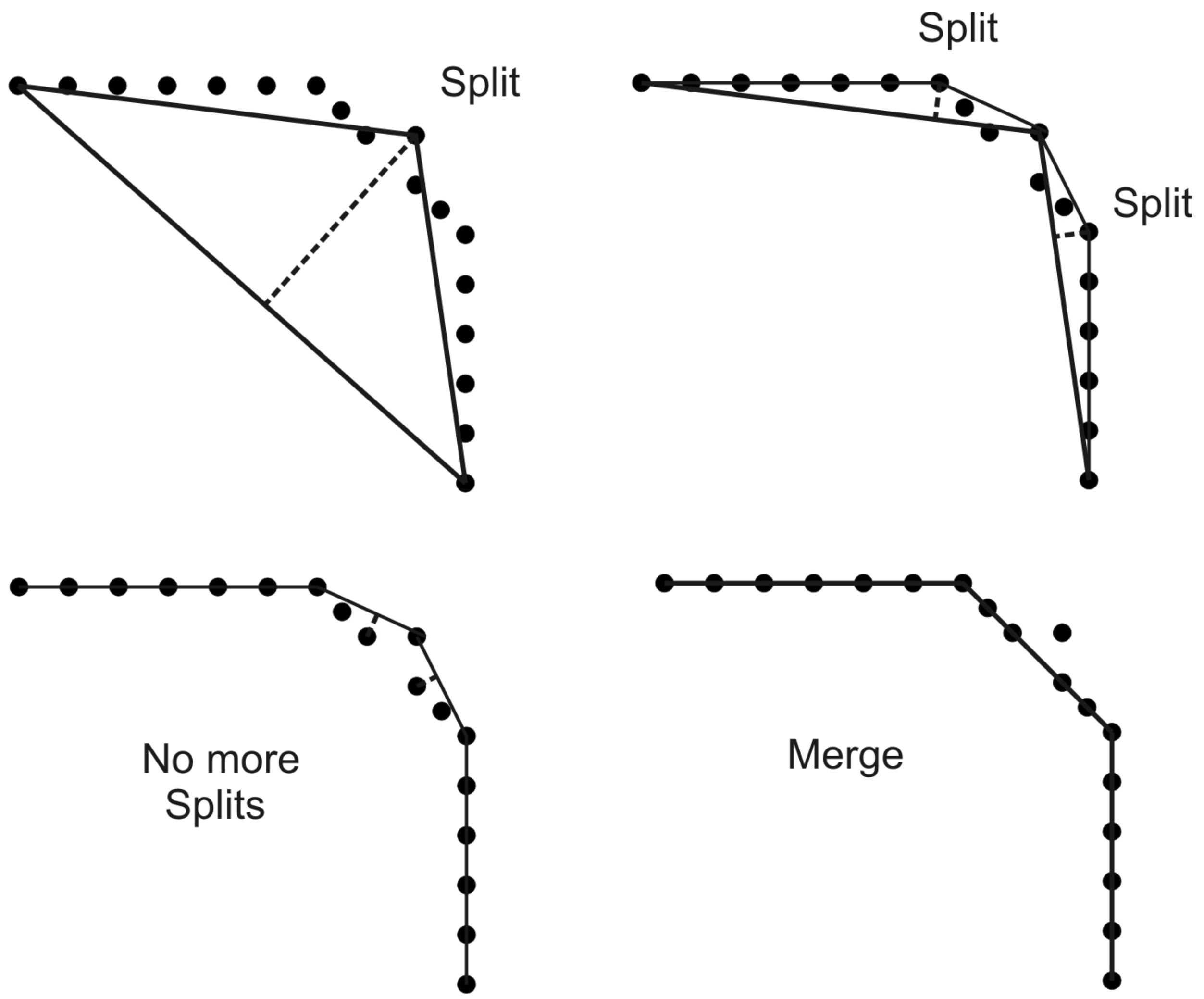
- The Algorithms we will see:
  1. Split and merge
  2. Linear regression
  3. RANSAC
  4. Hough-Transform

Algorithm 1: Split-and-Merge (standard)

- The most popular algorithm which is originated from computer vision.
- A recursive procedure of fitting and splitting.
- A slightly different version, called Iterative-End-Point-Fit, simply connects the end points for line fitting.



Algorithm 1: Split-and-Merge (Iterative-End-Point-Fit)

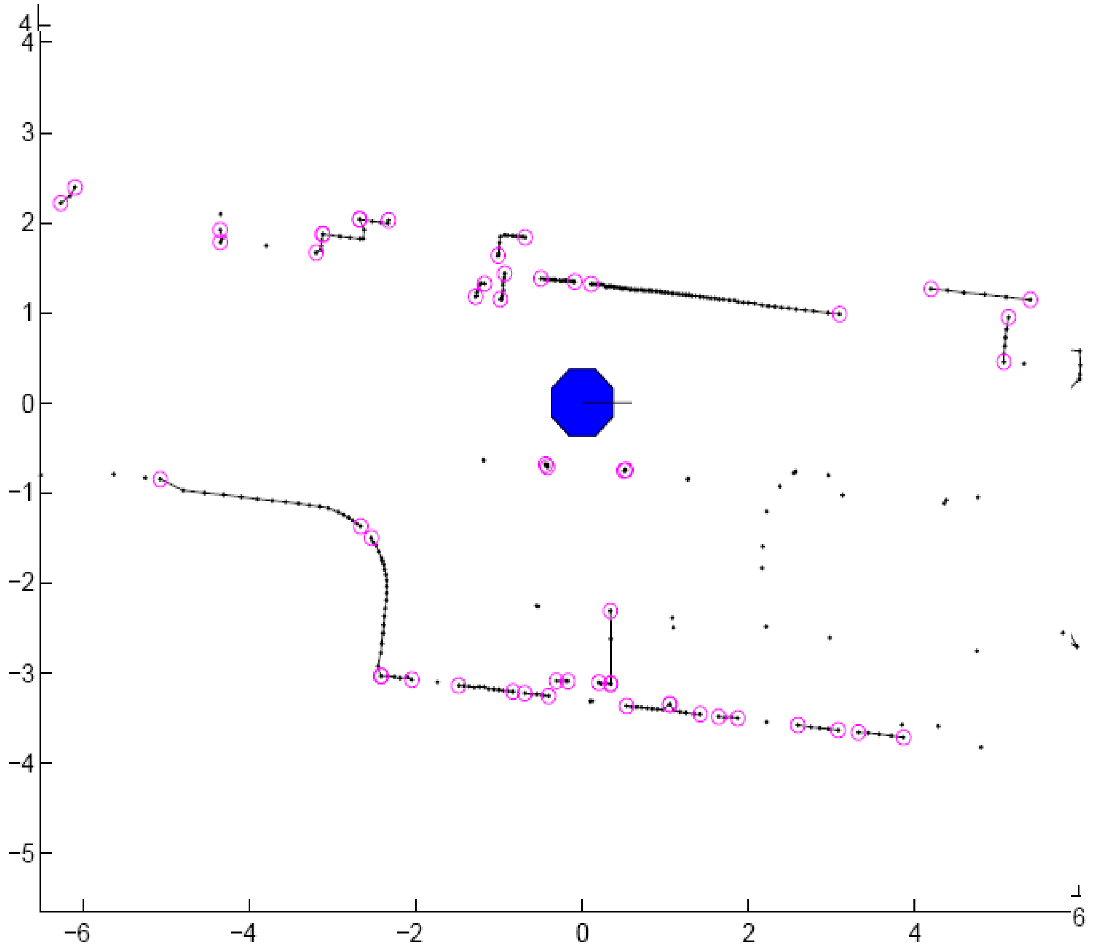


Algorithm 1: Split-and-Merge

Algorithm 1: *Split-and-Merge*

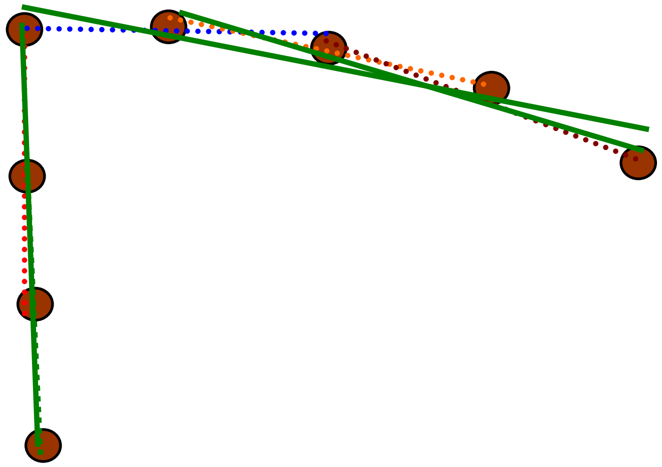
1. Initial: set s_1 consists of N points. Put s_1 in a list L
2. Fit a line to the next set s_i in L
3. Detect point P with maximum distance d_P to the line
4. If d_P is less than a threshold, continue (go to step 2)
5. Otherwise, split s_i at P into s_{i1} and s_{i2}, replace s_i in L by s_{i1} and s_{i2}, continue (go to 2)
6. When all sets (segments) in L have been checked, merge collinear segments.

Algorithm 1: Split-and-Merge: Example application



Algorithm 2: Line-Regression

- Uses a “sliding window” of size *Nf*
- The points within each “sliding window” are fitted by a segment
- Then adjacent segments are merged if their line parameters are close



$Nf = 3$

Algorithm 2: Line-Regression

Algorithm 2: *Line-Regression*

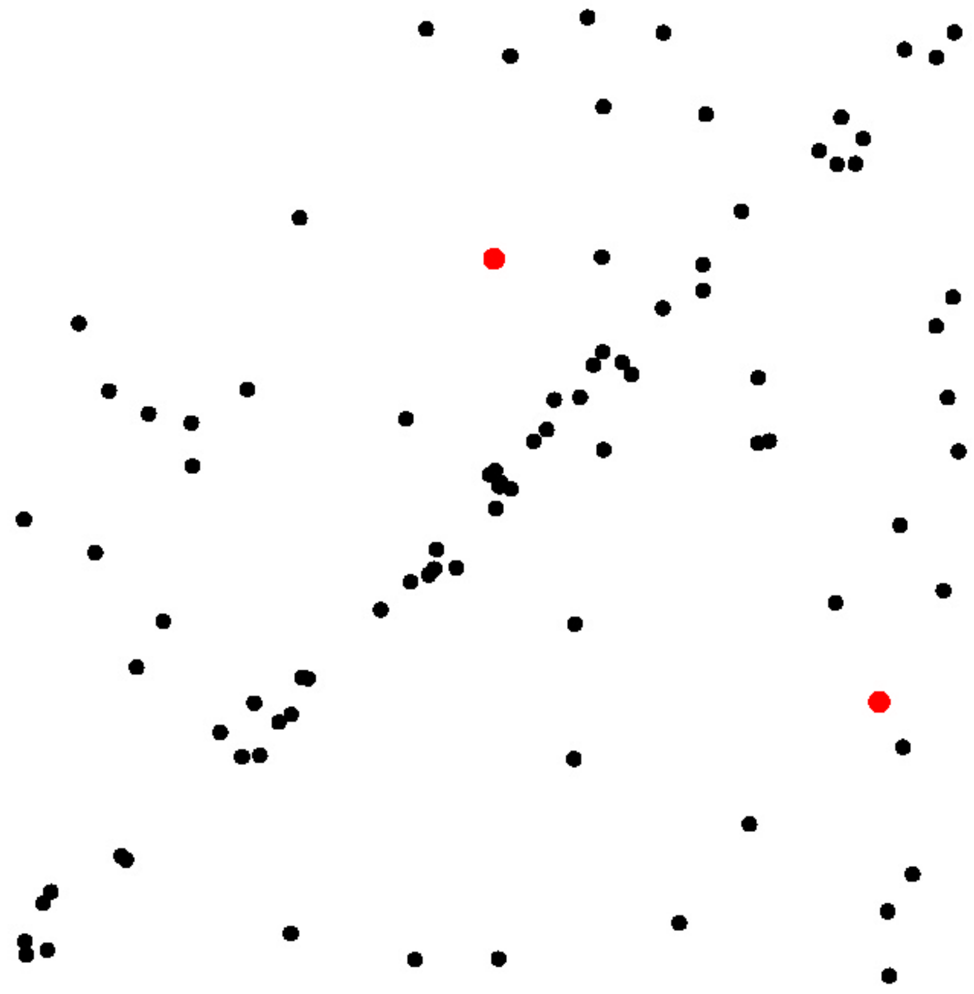
1. Initialize sliding window size N_f
2. Fit a line to every N_f consecutive points (a window)
3. Compute a line fidelity array, each is the sum of Mahalanobis distances between every three adjacent windows
4. Construct line segments by scanning the fidelity array for consecutive elements having values less than a threshold, using an AHC algorithm
5. Merge overlapped line segments and recompute line parameters for each segment

Algorithm 3: RANSAC

- Acronym of Random Sample Consensus.
- It is a generic and robust fitting algorithm of models in the presence of outliers (points which do not satisfy a model)
- RANSAC is not restricted to line extraction from laser data but it can be generally applied to any problem where the goal is to identify the inliers which satisfy a predefined mathematical model.
- Typical applications in robotics are: line extraction from 2D range data (sonar or laser); plane extraction from 3D range data, and structure from motion
- RANSAC is an iterative method and is non-deterministic in that the probability to find a line free of outliers increases as more iterations are used
- <u>Drawback: A nondeterministic method, results are different between runs.</u>

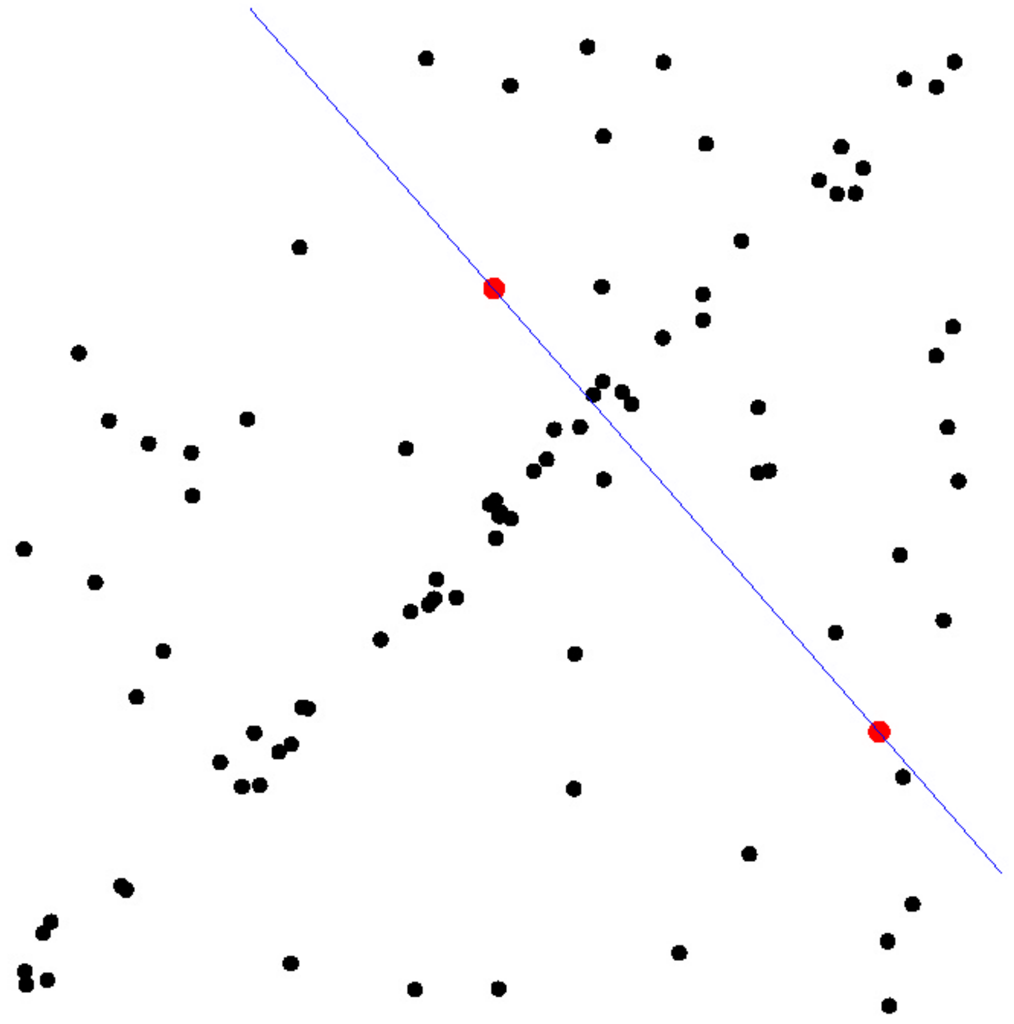
Algorithm 3: RANSAC

Algorithm 3: RANSAC



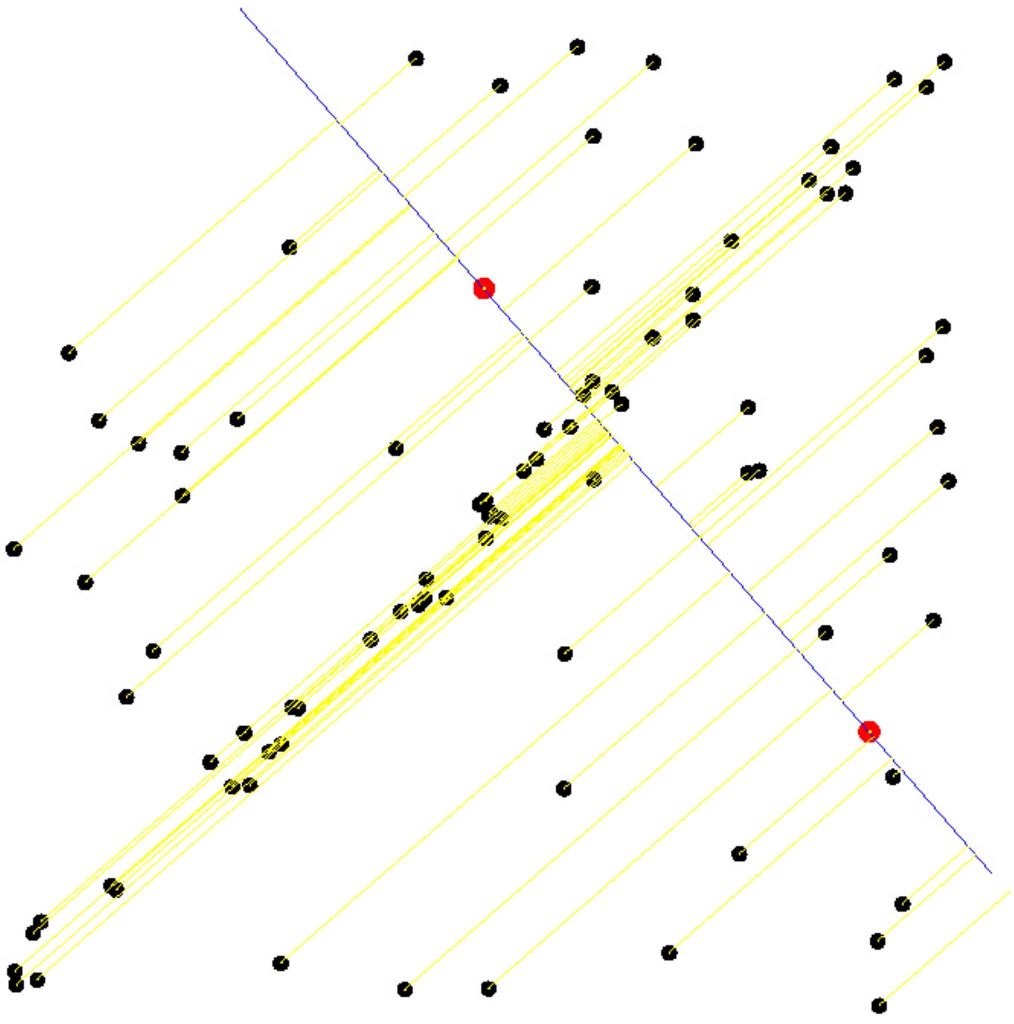
- **Select sample of 2 points at random**

Algorithm 3: RANSAC



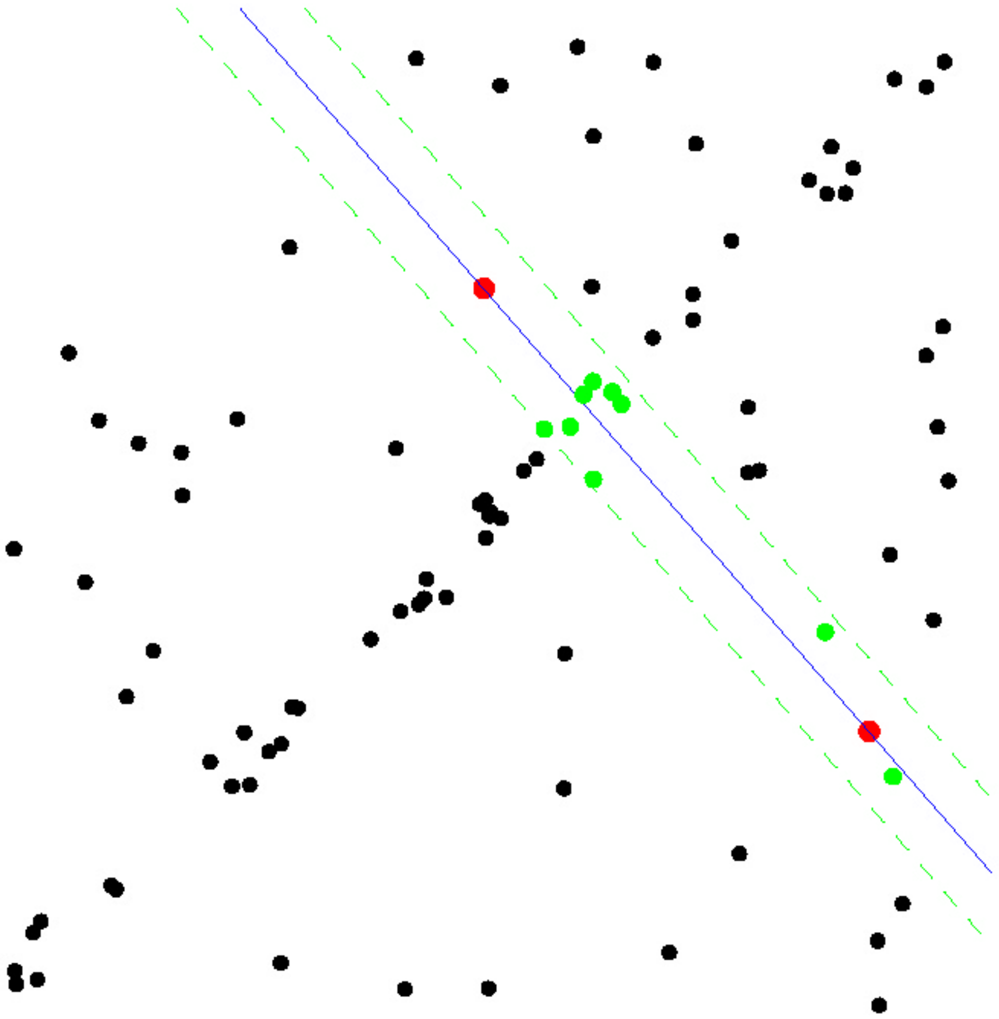
- Select sample of 2 points at random
- **Calculate model parameters that fit the data in the sample**

RANSAC



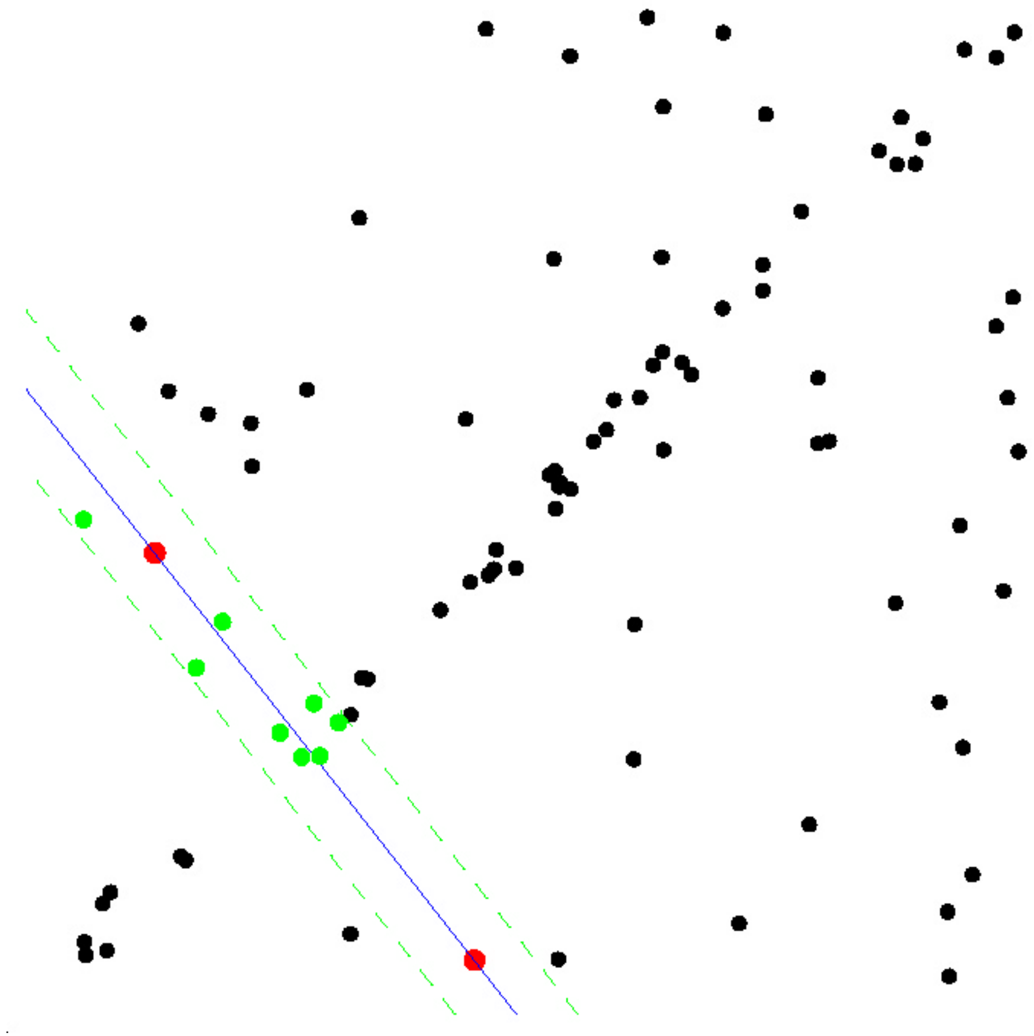
- Select sample of 2 points at random
- Calculate model parameters that fit the data in the sample
- **Calculate error function for each data point**

Algorithm 3: RANSAC



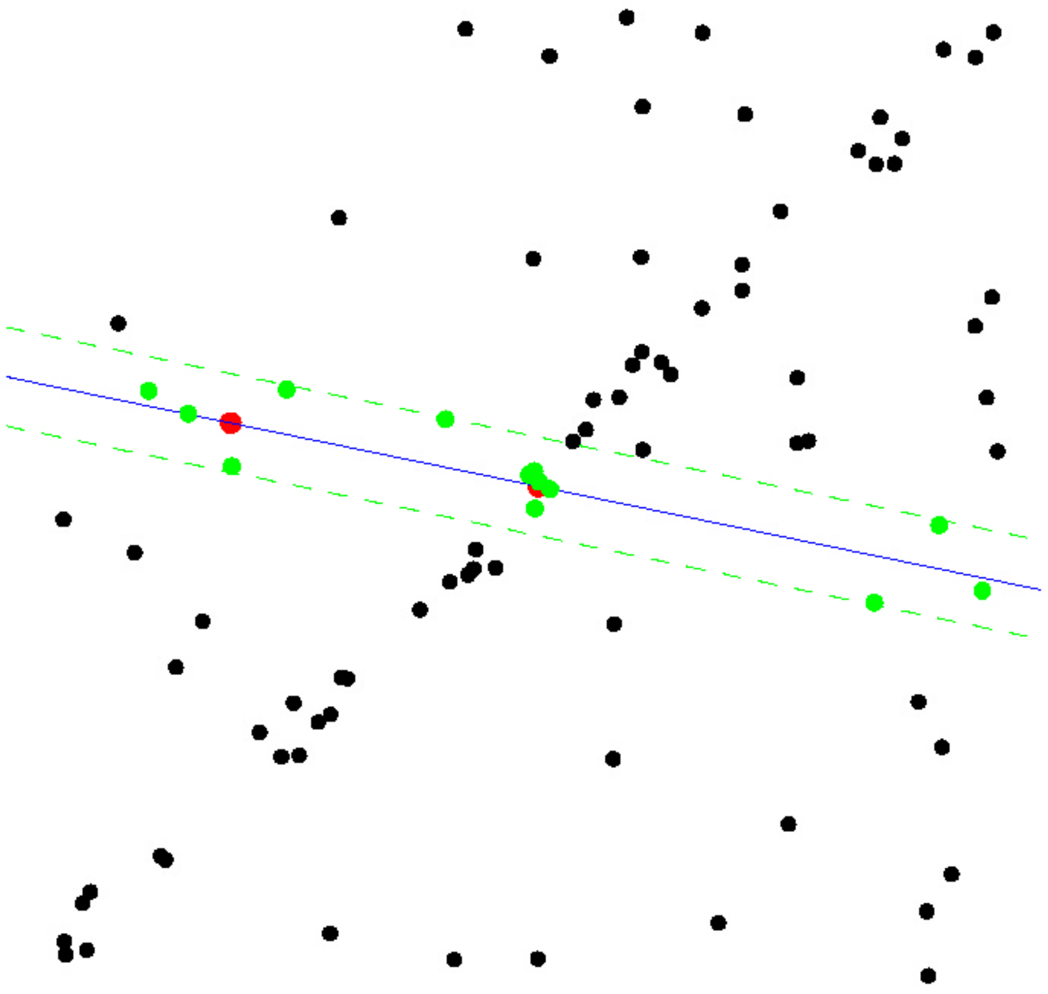
- Select sample of 2 points at random
- Calculate model parameters that fit the data in the sample
- Calculate error function for each data point
- **Select data that support current hypothesis**

Algorithm 3: RANSAC



- Select sample of 2 points at random
- Calculate model parameters that fit the data in the sample
- Calculate error function for each data point
- Select data that support current hypothesis
- **Repeat sampling**

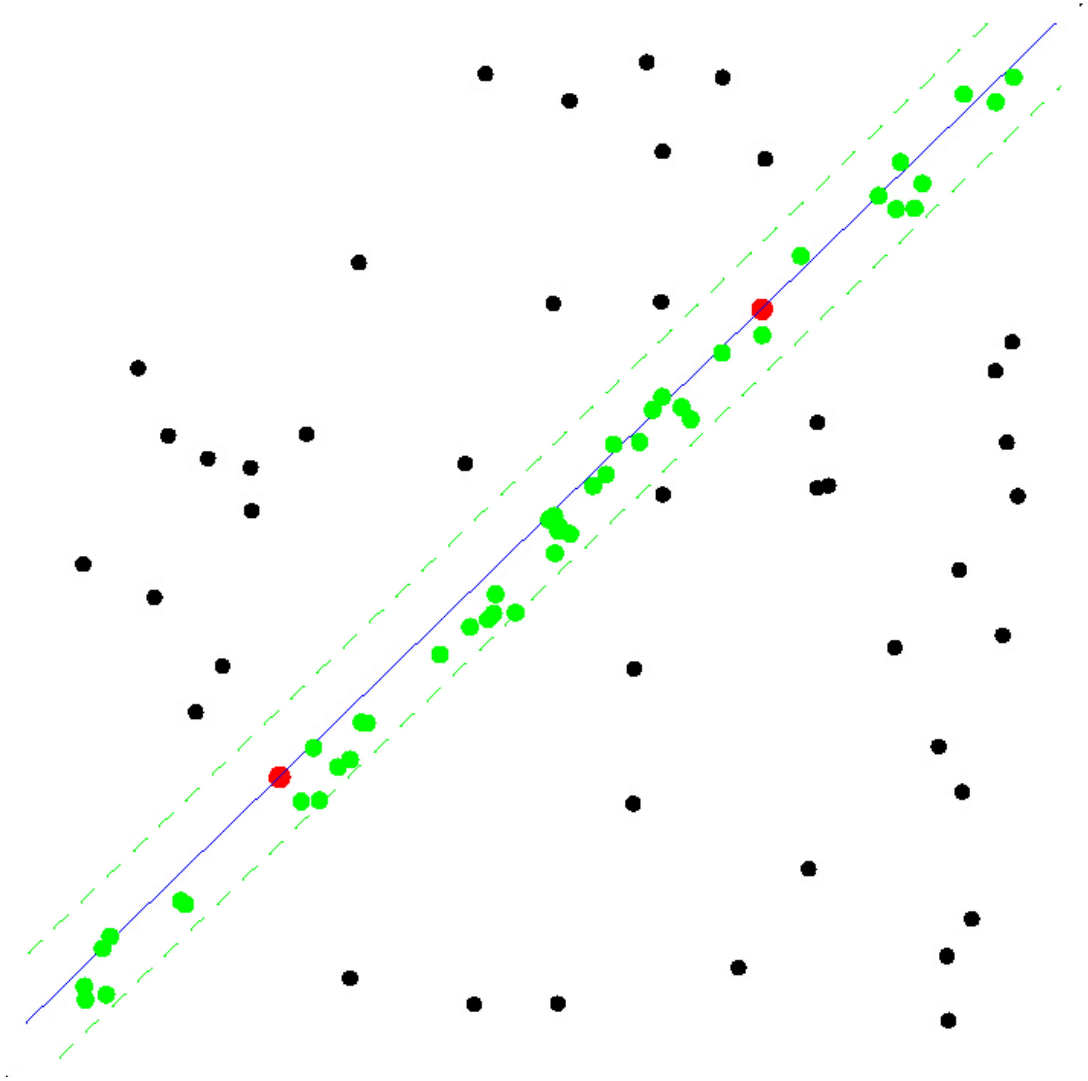
Algorithm 3: RANSAC



- Select sample of 2 points at random
- Calculate model parameters that fit the data in the sample
- Calculate error function for each data point
- Select data that support current hypothesis
- **Repeat sampling**

Algorithm 3: RANSAC

ALL-INLIER SAMPLE



Algorithm 3: RANSAC

Algorithm 4: *RANSAC*

1. Initial: let A be a set of N points
2. **repeat**
3. Randomly select a sample of 2 points from A
4. Fit a line through the 2 points
5. Compute the distances of all other points to this line
6. Construct the inlier set (i.e. count the number of points with distance to the line $< d$)
7. Store these inliers
8. **until** Maximum number of iterations k reached
9. The set with the maximum number of inliers is chosen as a solution to the problem

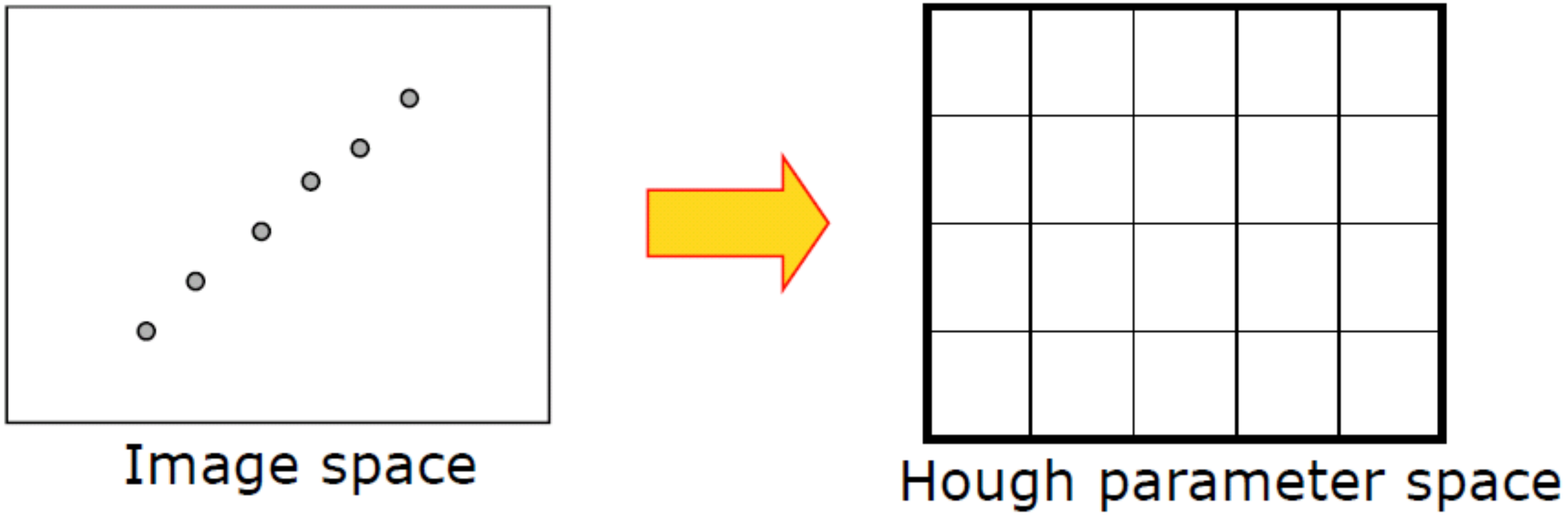
Algorithm 3: RANSAC

How many iterations does RANSAC need?

- Because we cannot know in advance if the observed set contains the maximum number of inliers, the ideal would be to check all possible combinations of 2 points in a dataset of N points.
- The number of combinations is given by N(N-1)/2, which makes it computationally unfeasible if N is too large. For example, in a laser scan of 360 points we would need to check all 360*359/2= 64,620 possibilities!
- Do we really need to check all possibilities or can we stop RANSAC after iterations? The answer is that indeed we do not need to check all combinations but just a subset of them if we have a rough estimate of the percentage of inliers in our dataset
- This can be done in a probabilistic way

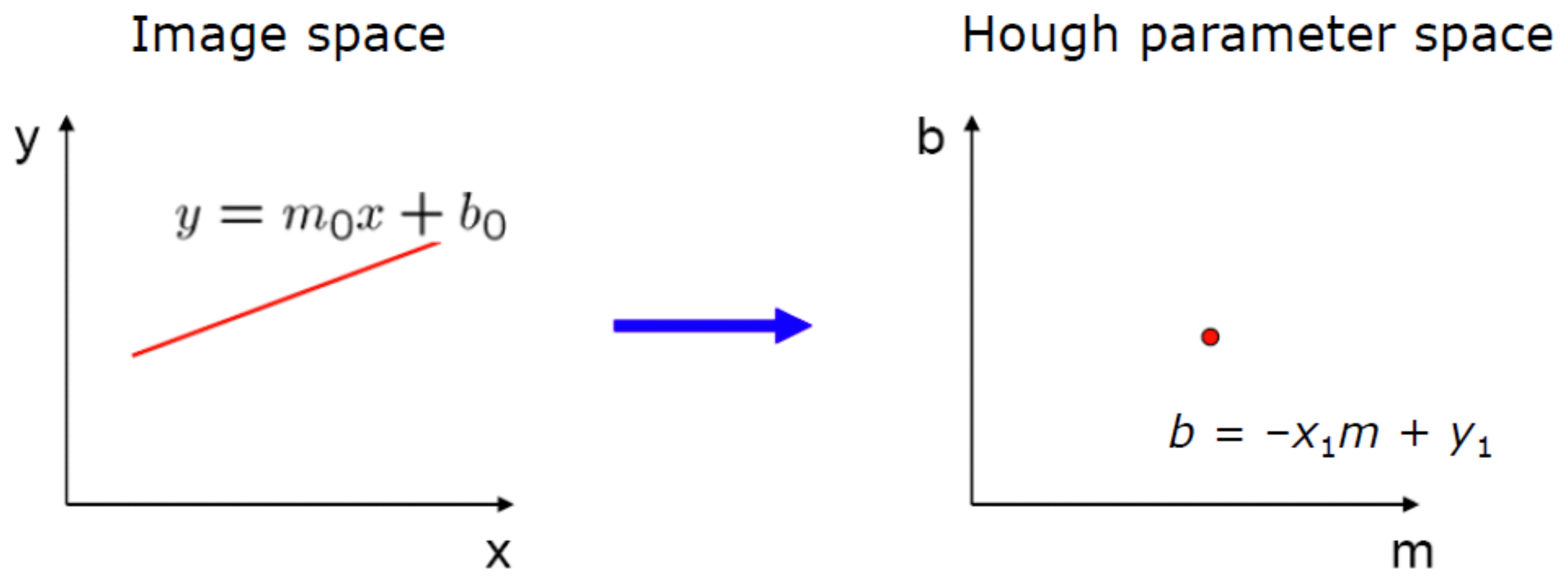
Algorithm 4: Hough-Transform

- Hough Transform uses a voting scheme



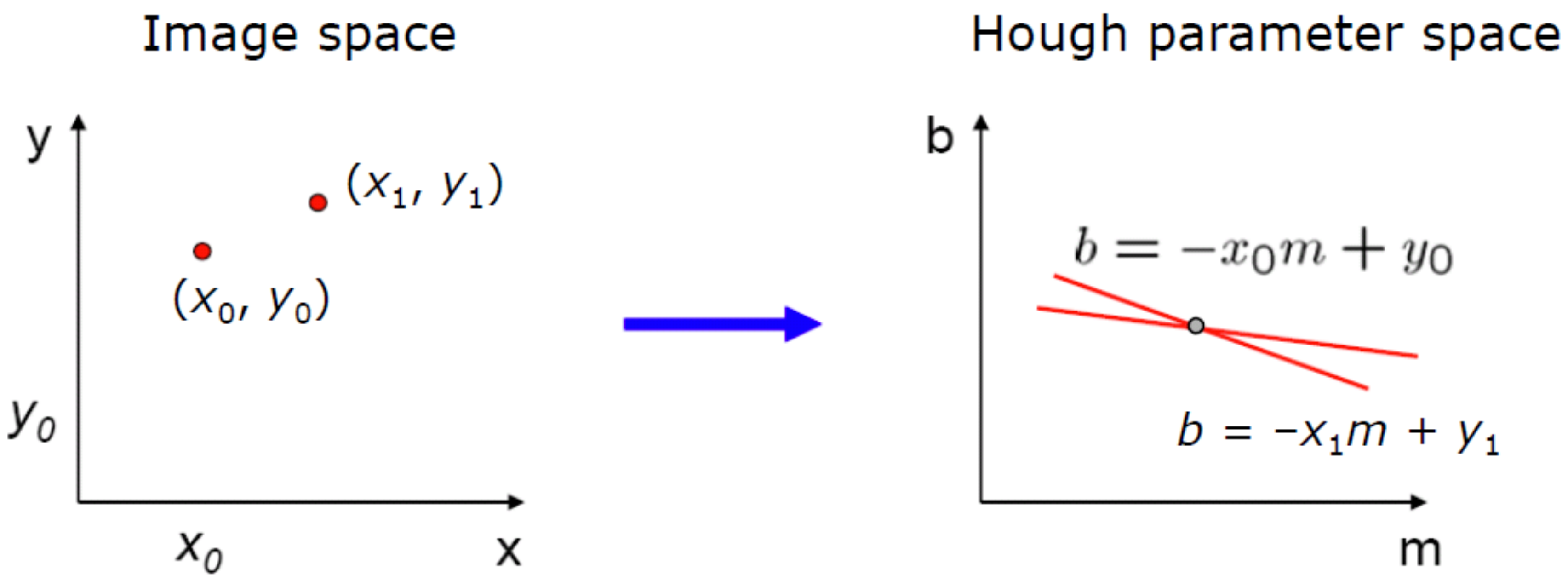
Algorithm 4: Hough-Transform

- A line in the image corresponds to a point in Hough space



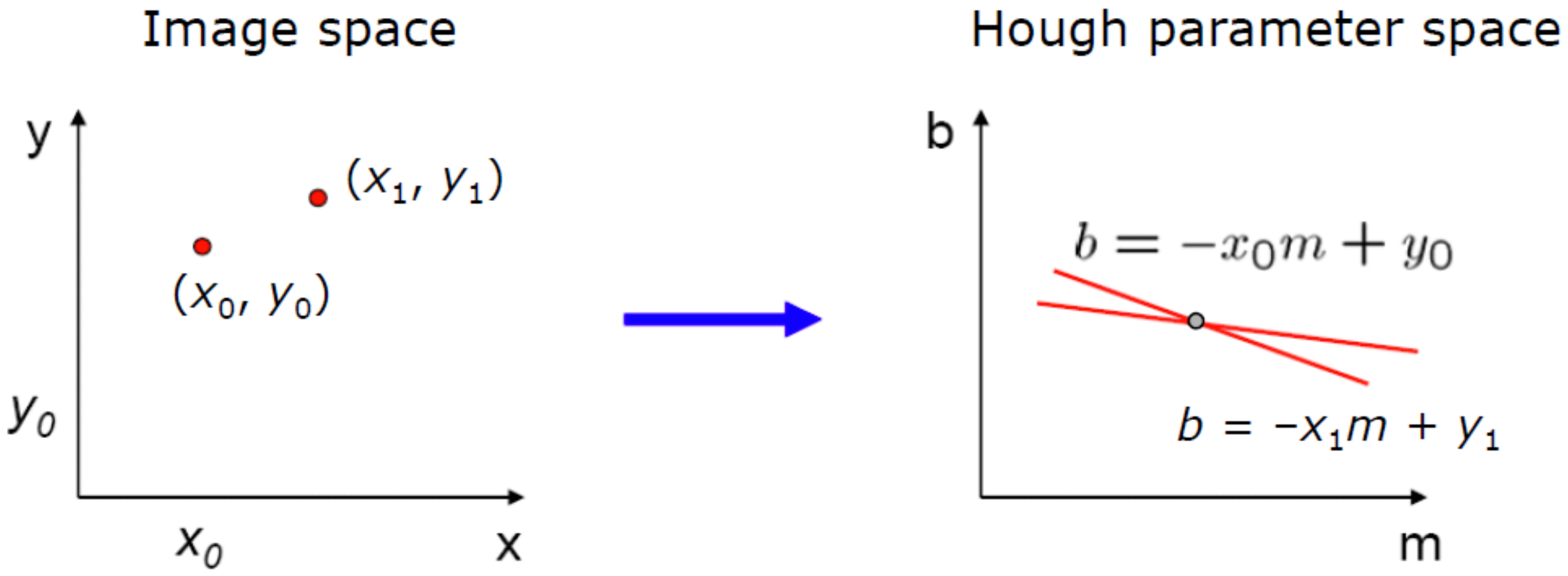
Algorithm 4: Hough-Transform

- What does a point (x_0, y_0) in the image space map to in the Hough space?



Algorithm 4: Hough-Transform

- Where is the line that contains both (x_0, y_0) and (x_1, y_1)?
  - It is the intersection of the lines $b = -x_0 m + y_0$ and $b = -x_1 m + y_1$



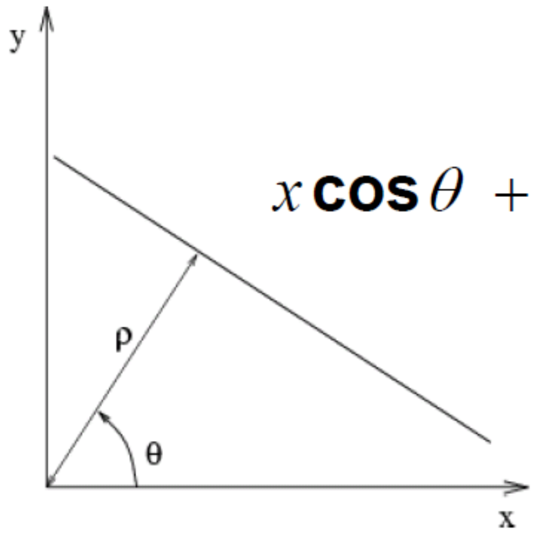
Algorithm 4: Hough-Transform

- Problems with the (m,b) space:
  - Unbounded parameter domain
  - Vertical lines require infinite m

Algorithm 4: Hough-Transform

- Problems with the (m,b) space:
  - Unbounded parameter domain
  - Vertical lines require infinite m

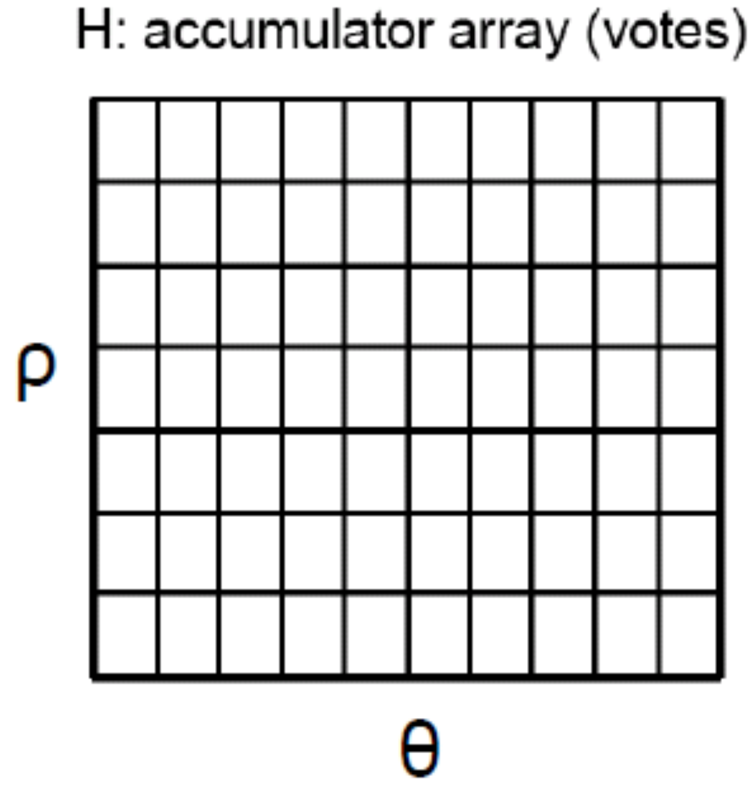
- Alternative: polar representation



$$x \cos\theta + y \sin\theta = \rho$$

Each point will add a sinusoid in the (θ,ρ) parameter space

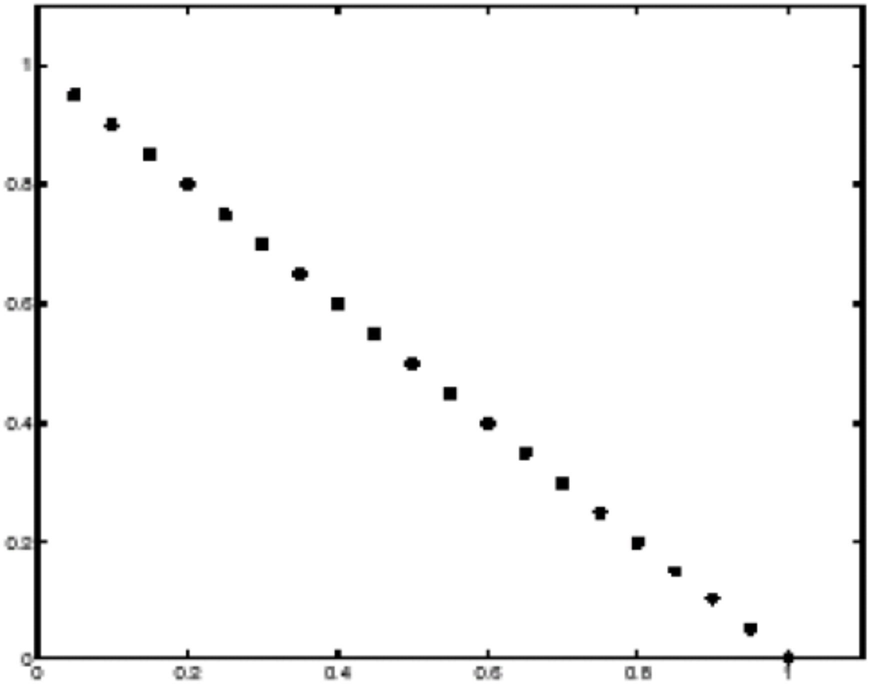
Algorithm 4: Hough-Transform



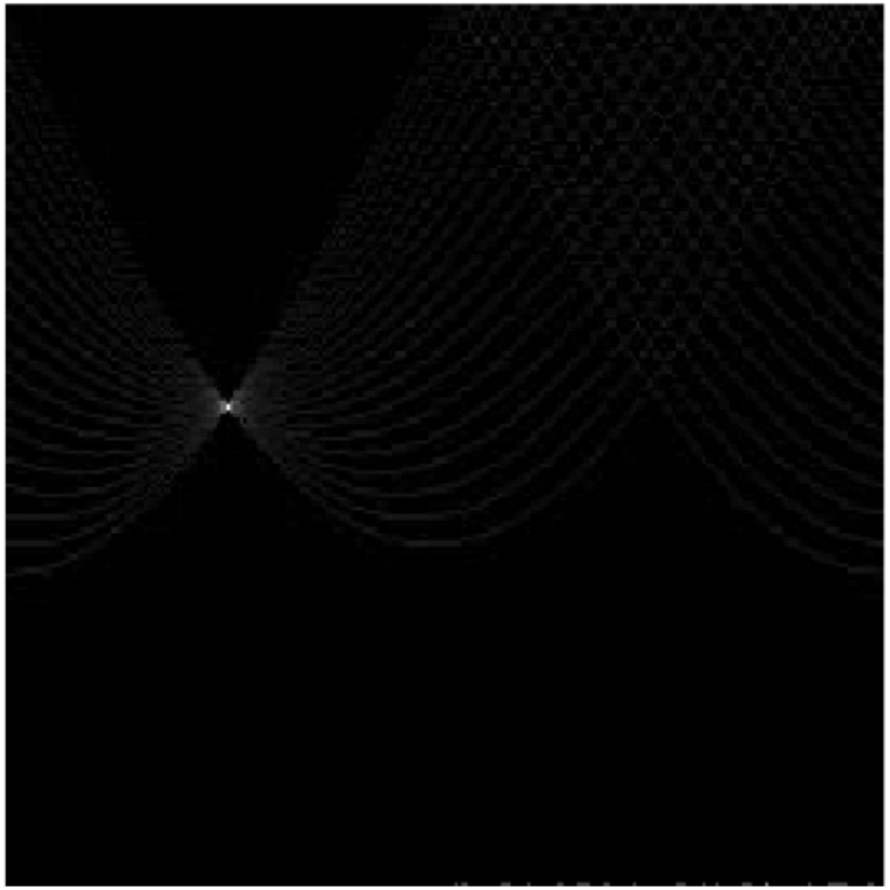
1. Initialize accumulator H to all zeros
2. For each edge point (x,y) in the image
   - For $\theta = 0$ to 180 (with a step size of e.g. 18)
     - $\rho = x \cos\theta + y \sin\theta$
     - $H(\theta, \rho) = H(\theta, \rho) + 1$
   - end

   end
3. Find the values of (θ, ρ) where $H(\theta, \rho)$ is a local maximum
4. The detected line in the image is given by $\rho = x \cos\theta + y \sin\theta$

Algorithm 4: Hough-Transform



features

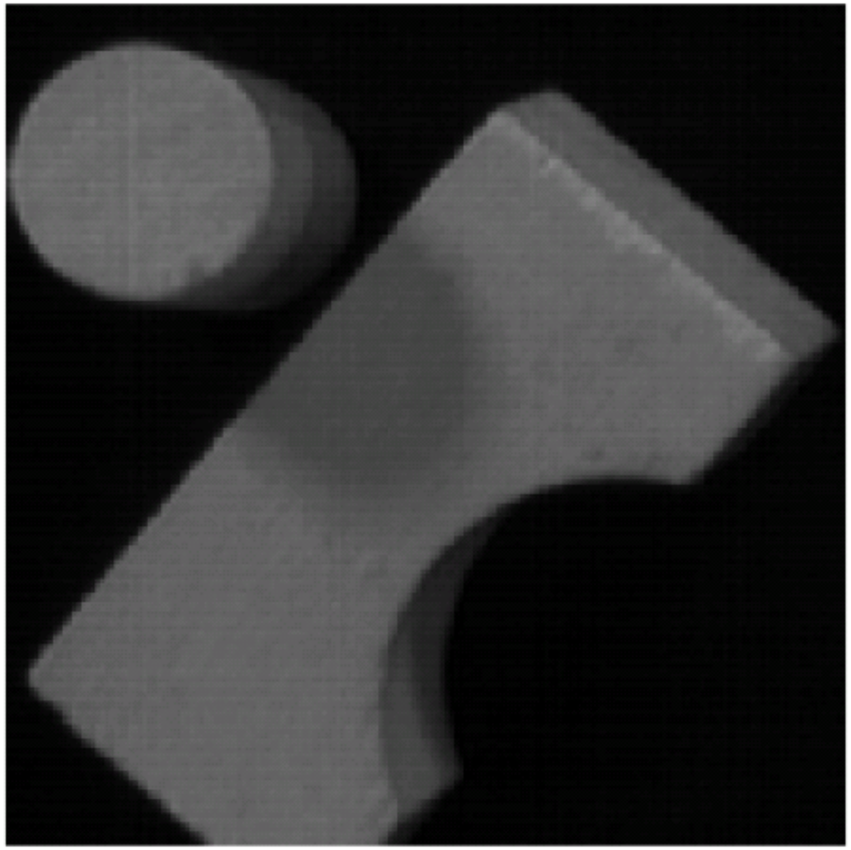


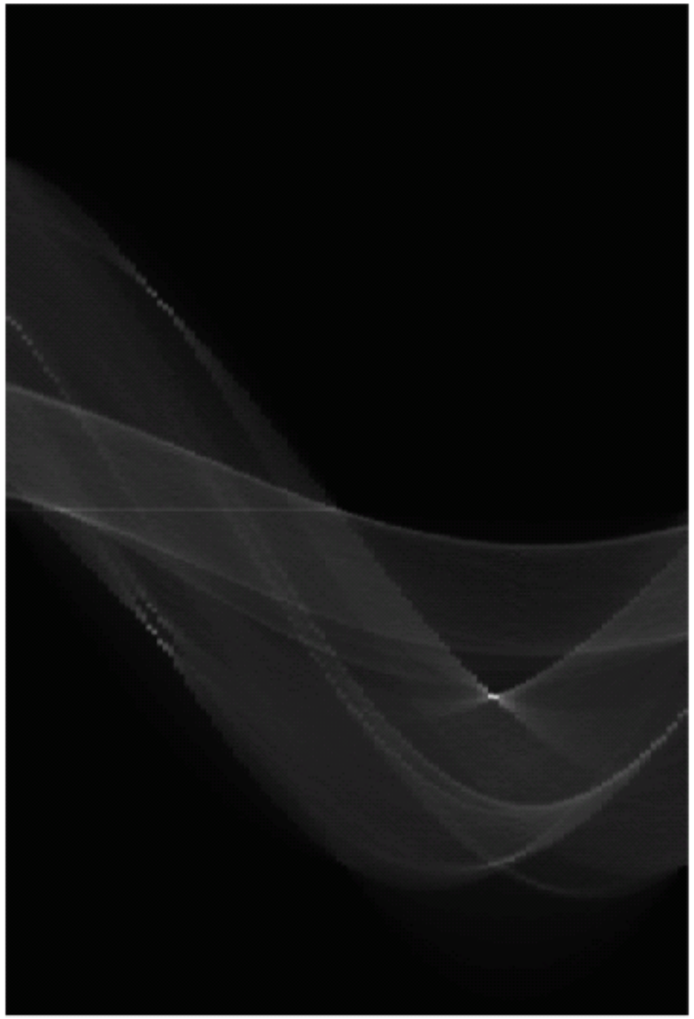
votes

Algorithm 4: Hough-Transform

Square

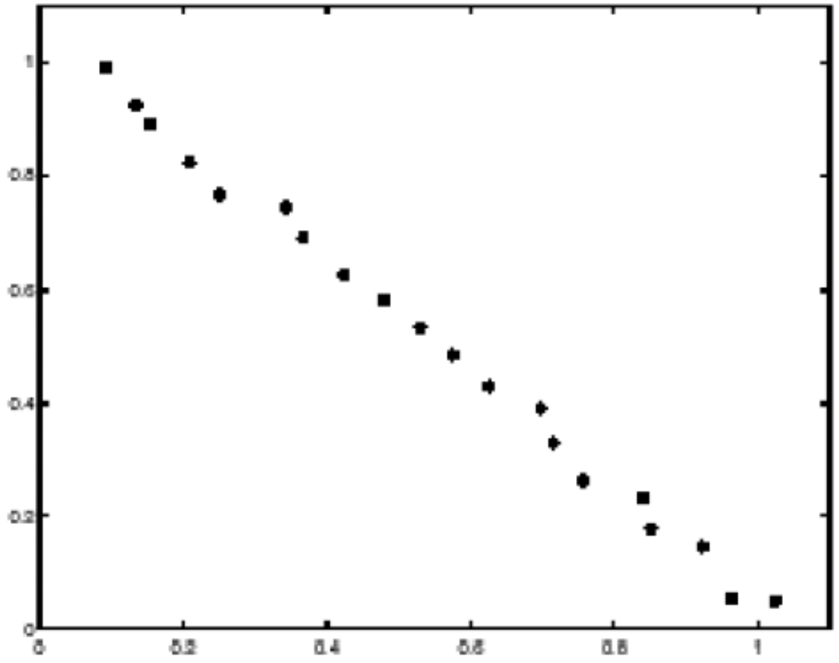
Algorithm 4: Hough-Transform



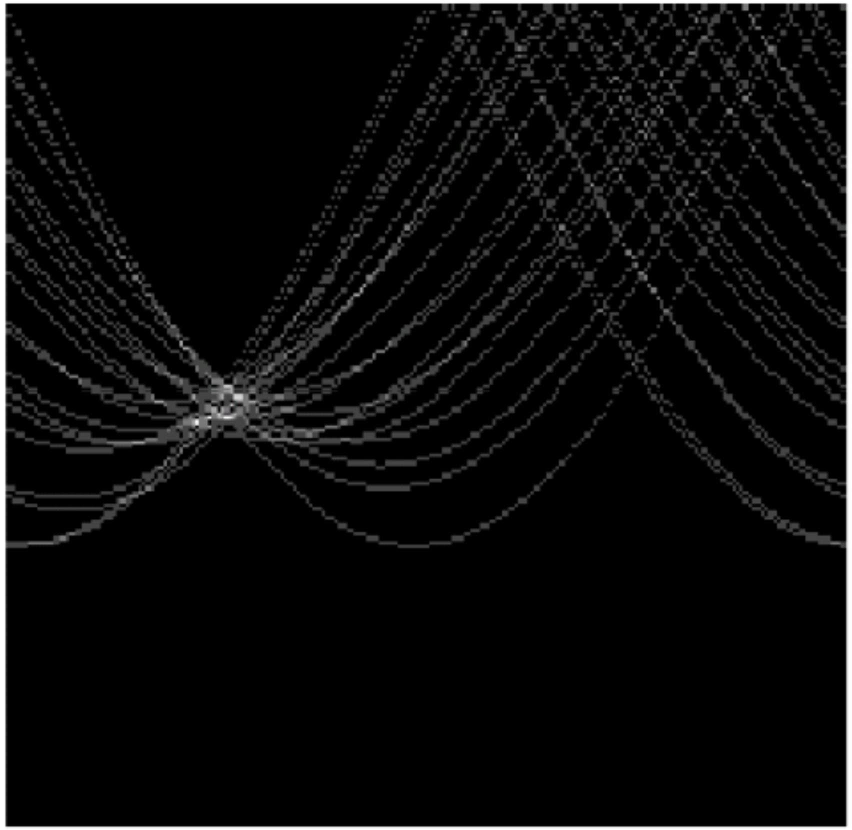


Algorithm 4: Hough-Transform

Effect of Noise



features



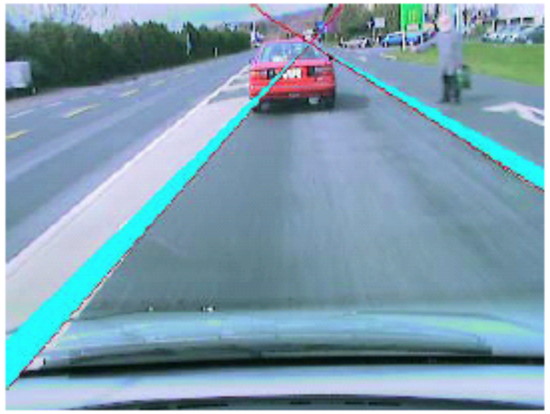
votes

- Peak gets fuzzy and hard to locate

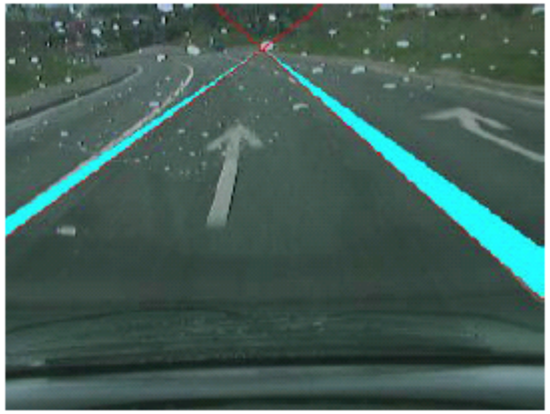
Algorithm 4: Hough-Transform

Application: Lane detection

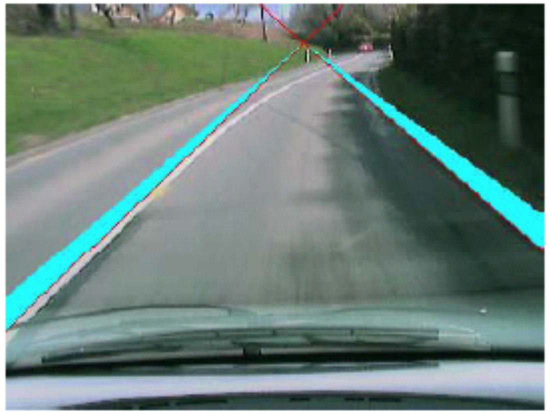
Inner city traffic



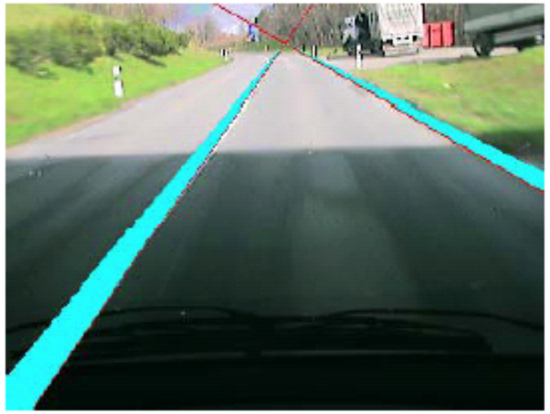
Ground signs



Country-side lane

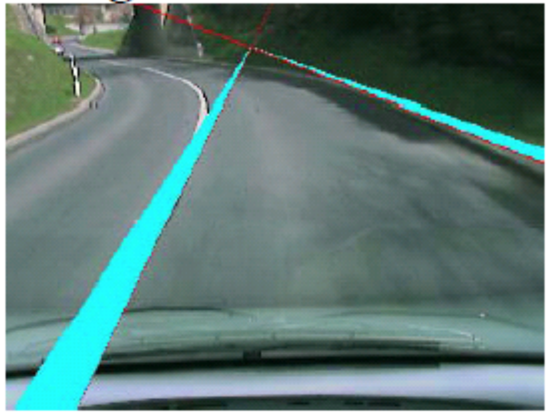


Tunnel exit

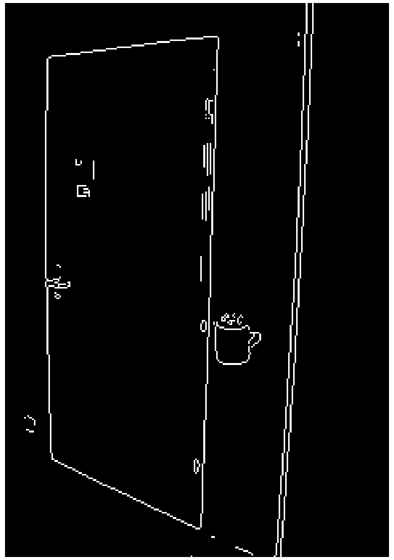


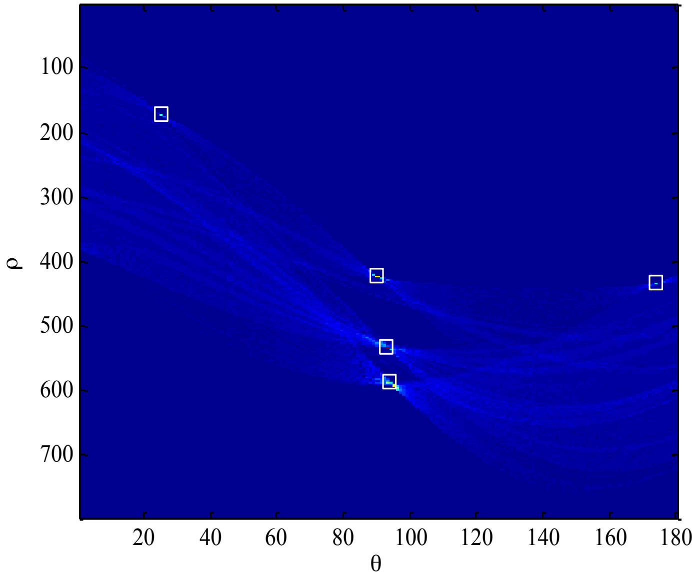
Obscured windscreen

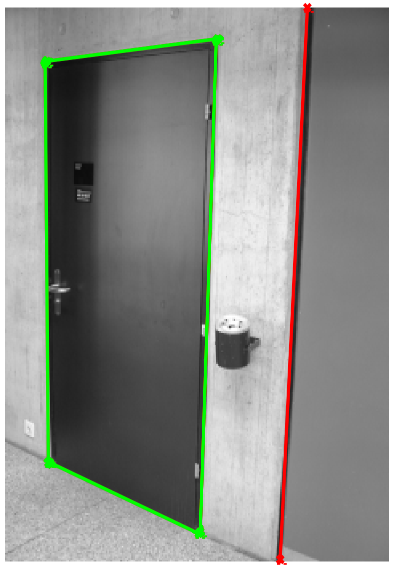
High curvature



Example – Door detection using Hough Transform







Hough Transform

Hough Transform: other features

Lines:

$$p = (d, \upsilon)$$

$$g(x, y, p) := x \cdot \cos(\upsilon) + y \cdot \sin(\upsilon) - d$$

Circles:

$$p = (x_0, y_0, r)$$

$$g(x, y, p) := (x - x_0)^2 + (y - y_0)^2 - r^2$$

Ellipses:

$$p = (x_0, y_0, a, b, \psi)$$

$$g(x, y, p) := \frac{\left[(x - x_0) \cdot \cos(\psi) + (y - y_0) \cdot \sin(\psi)\right]^2}{a^2} + \frac{\left[(y - y_0) \cdot \cos(\psi) - (x - x_0) \cdot \sin(\psi)\right]^2}{b^2} - 1$$

Hough Transform

- Advantages
  - Noise and background clutter do not impair detection of local maxima
  - Partial occlusion and varying contrast are minimized
- Negatives
  - Requires time and space storage that increases exponentially with the dimensions of the parameter space

Comparison **Line Detection**

- Deterministic methods perform better with laser scans
  - Split-and-merge, Line-Regression, Hough transform
  - Make use of the sequencing property of scan points.
- Nondeterministic methods can produce high False Positives
  - RANSAC
  - Do not use the sequencing property
  - But it can cope with outliers
- Overall:
  - Split-and-merge is the fastest, best real-time applications