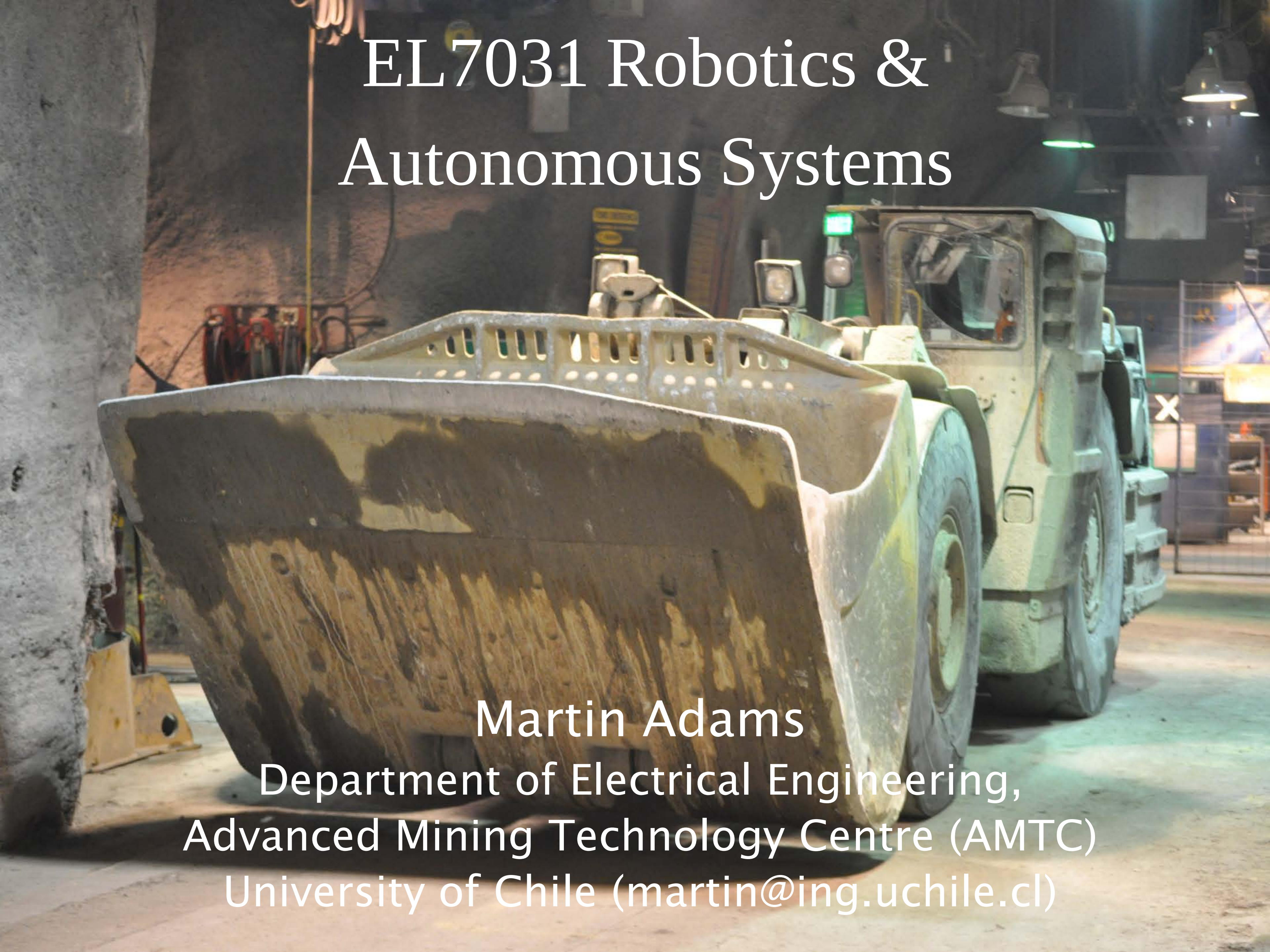

EL7031 Robotics & Autonomous Systems

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Department of Electrical Engineering,
Advanced Mining Technology Centre (AMTC)
University of Chile (martin@ing.uchile.cl)

Presentation Outline

1. Autonomous Robotics in Society.
2. Robotics Research at ARRL.
   - Radar Mapping & Traffic Monitoring.
   - Coastal and Marine Monitoring.
   - Feature Extraction with Vision/3D Laser Range Data.
3. Simultaneous Localisation & Map Building (SLAM).
   - What is SLAM – Fundamentals?
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Autonomy in Urban Environments

DARPA Urban Challenge.
Sensor based road lane & pedestrian detection.

Perform complex manoeuvres – merging, passing, parking, interaction with manned vehicles [Thrun 2007, Leonard 2007].

Singapore: TechX Challenge

Localisation, Path Planning, Object Recognition & Interaction [Adams 2009].

Autonomy in Mines/Rugged Terrains

Rio Tinto + ACFR developing autonomous mining technologies [Durrant-Whyte 2007]

Codelco developing unmanned haulage system "FrontRunner" at Gaby copper mine, Chile [Komatsu 2007]

].

Sensing Issues:
Millimetre Wave Radar in Surface Mining
[Brooker 2006].

Intelligent Transportation Systems (ITS)

Platooning and Vehicle Following. Optimisation and monitoring of traffic flow needed. [Martinet et. al. 2005, Broggi 2000, Parent 1996].

ITS Austria: Traffic monitoring & optimisation. [Corvette/Connect Projects].

INRIA (Schiphol/Heathrow Airport Passenger Pick up).

Service Robotics

Autonomous straddle carriers – ACFR port automation projects in Brisbane & Singapore, [Durrant-Whyte 2007].

Autonomous Straddle Carrier in Operation

Hospital vehicles for delivery of food/laundry in Singapore [Swisslog].

Rehabilitation robotics [Tomatis - BlueBotics 2008]

Security Robotics

Surveillance and monitoring vehicles capable of indoor/outdoor motion. [Adams 2004].

KIRAS – Security Research [Austrian FFG – protection of infrastructure].

Security Robotics

Surveillance and monitoring vehicles capable of indoor/outdoor motion. [Adams 2004].

KIRAS – Security Research [Austrian FFG – protection of infrastructure].

Remaining issues:

Sensor modelling & fusion.

Robust localisation/object representation – SLAM in complex environments.

System Flexibility: Path re-planning/unexpected situations.

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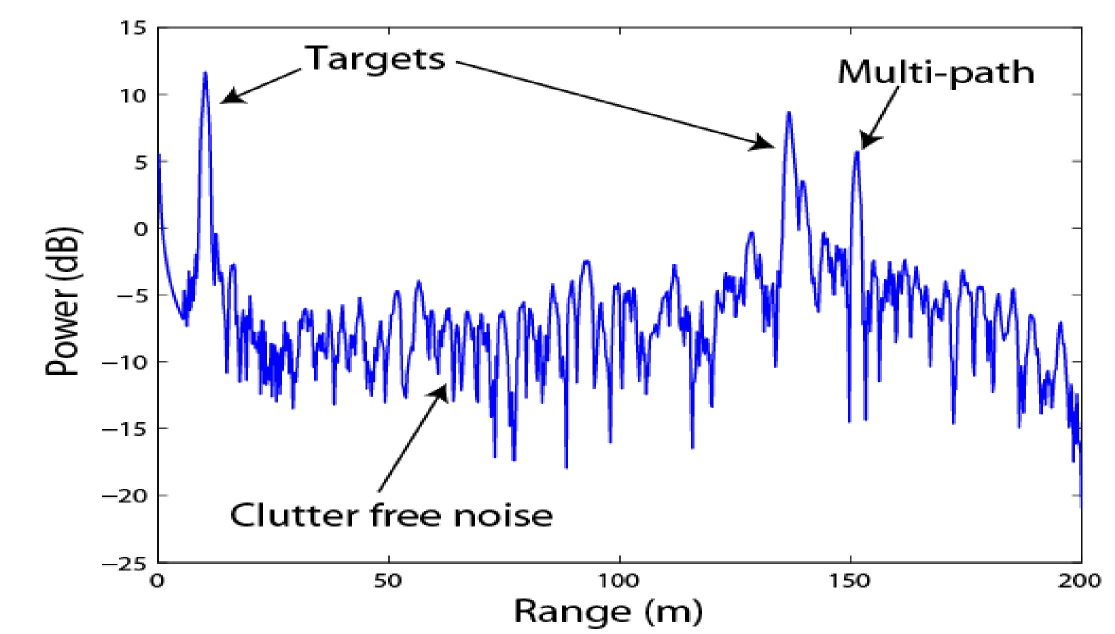
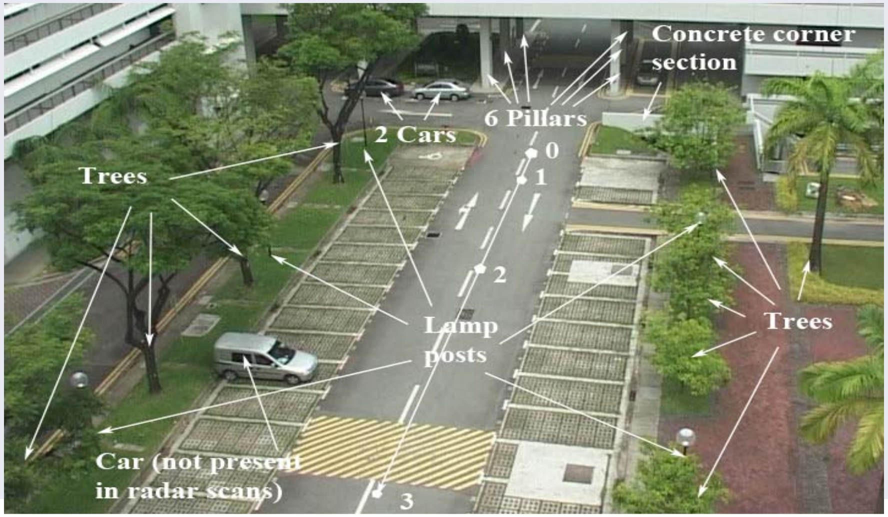
Panasonic: People & Traffic Detection with Radar

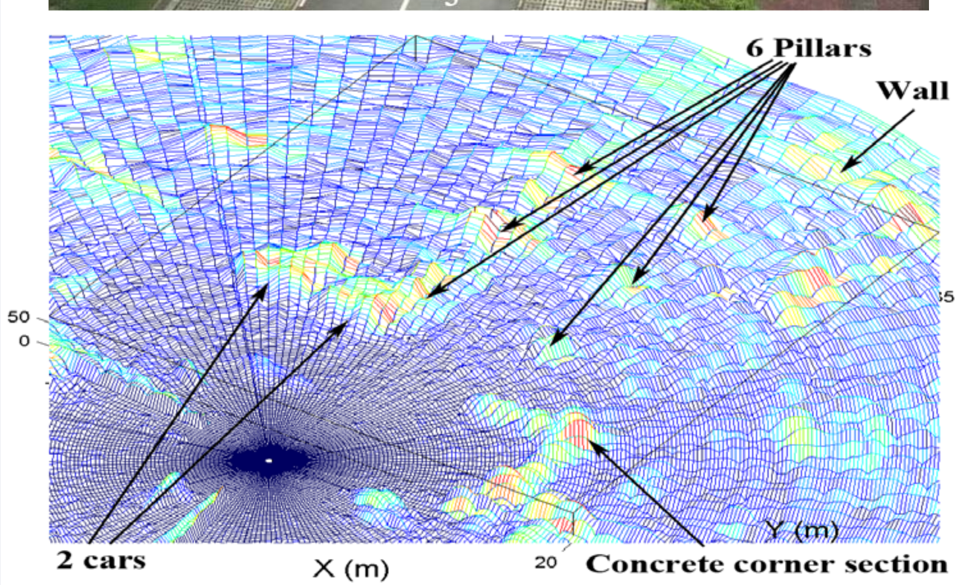
Millimetre Wave Radar

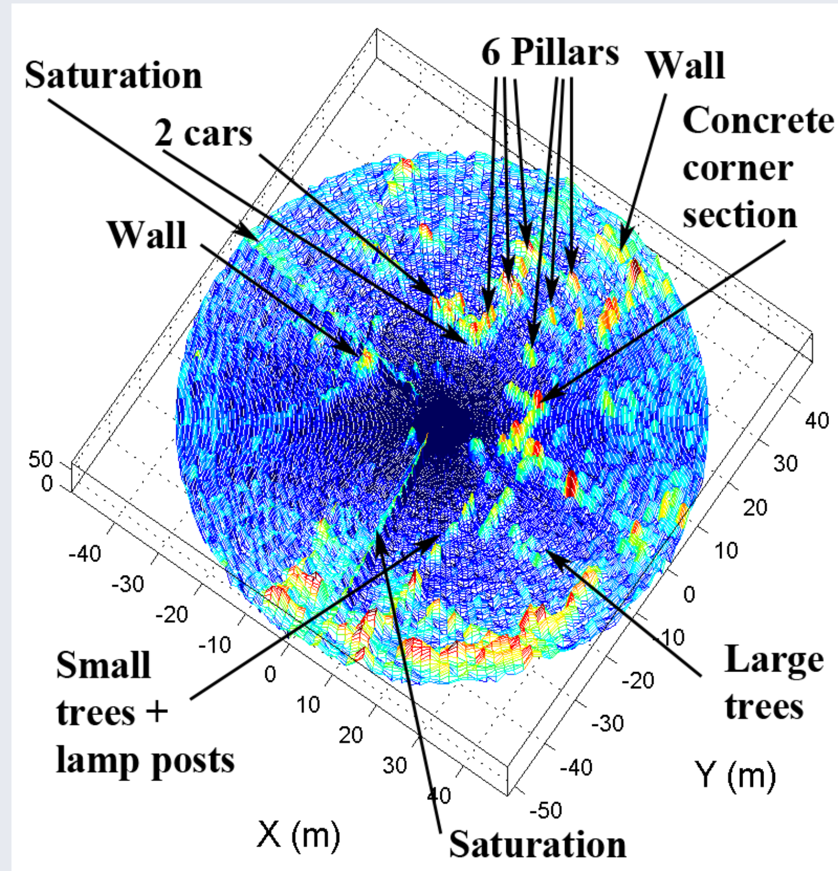
- 360 deg. scanning unit, 77GHz FMCW
- 0.25m range res., 200m max range
- Per Bearing angle -> Multiple Targets
- 1.8 deg. beam width



Advantages of Radar

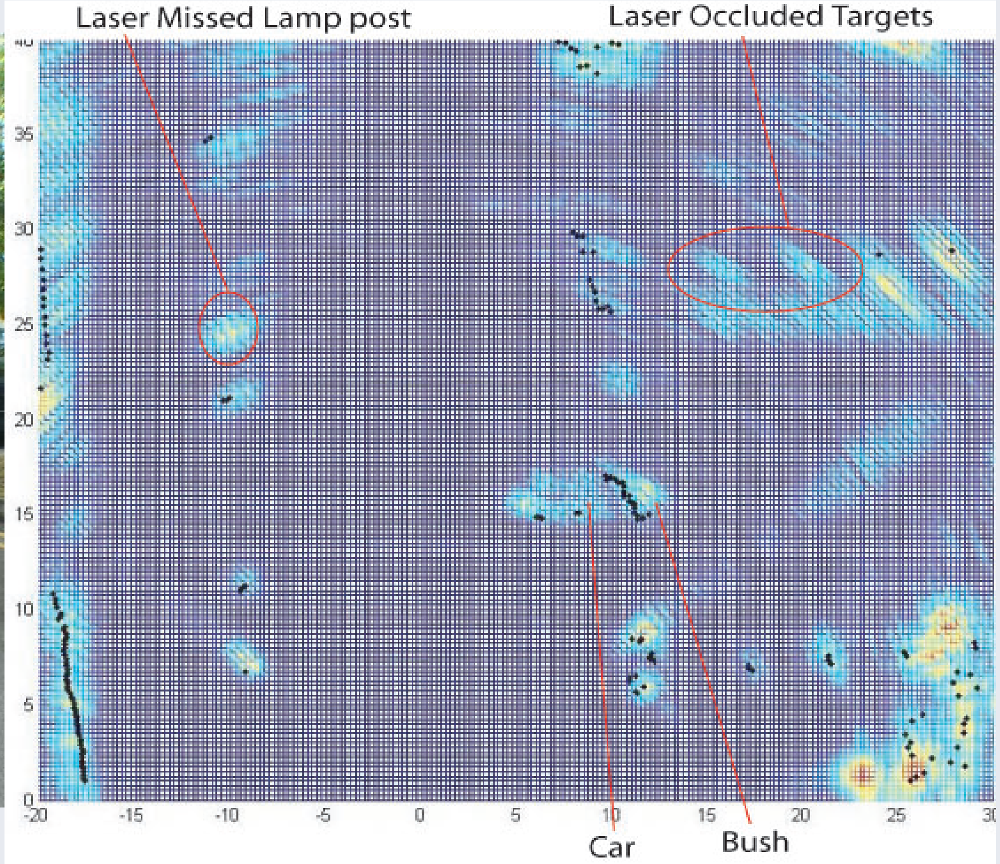






Advantages of Radar

- ✓ **Wider beam width**
- ✓ **Foliage penetration**



Panasonic: People Tracking at Road Junctions

Transverse Length of road crossing: 13m

Road crossing13m from radar (min. detection range 5m)

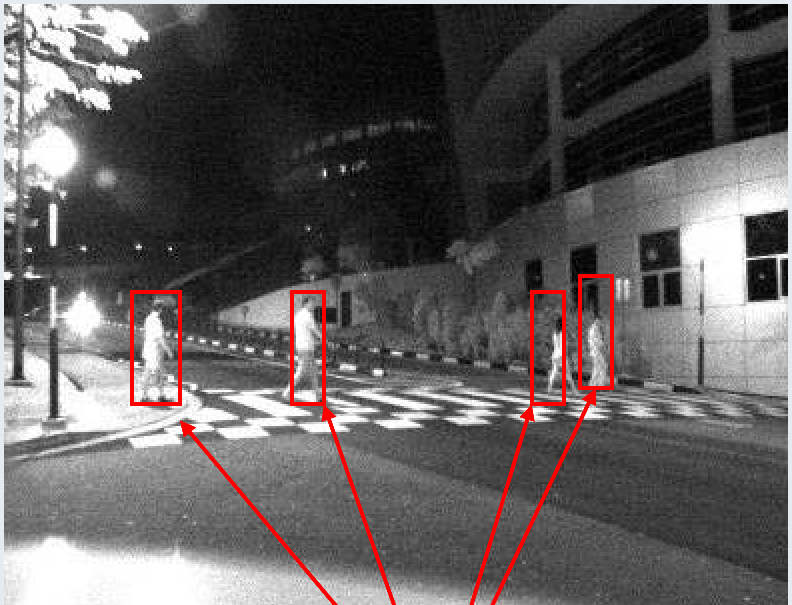
- Use of Radar for adverse weather/atmospheric conditions.
- Robust detection of pedestrians and traffic [Mullane, Adams 2009]
- Purpose: To transmit traffic information to drivers for advanced warning systems.

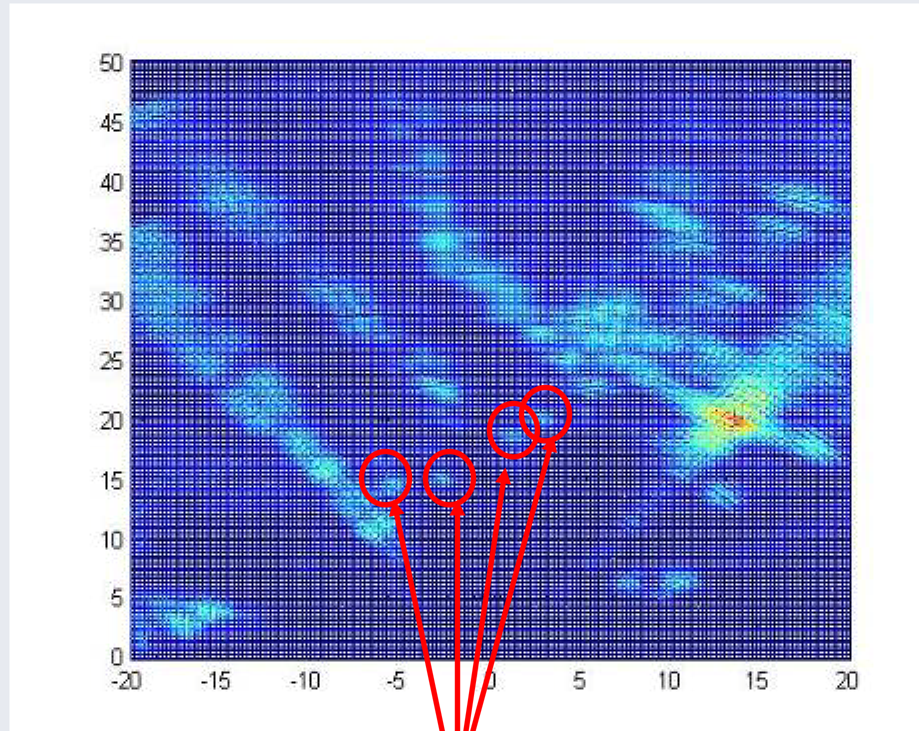
Location: A pedestrian crossing within NTU campus

Vid. 2

Panasonic: People Tracking at Road Junctions

Road crossing environment (Near IR image Vs. Radar image)





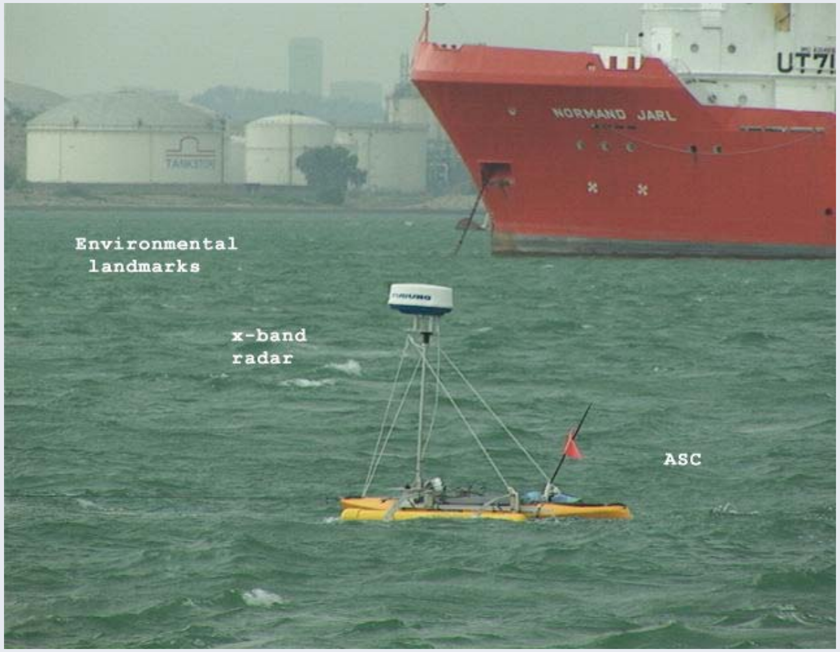
4 Pedestrians crossing

4 Pedestrian targets detected

At Night

Singapore – MIT Alliance: CENSAM Project

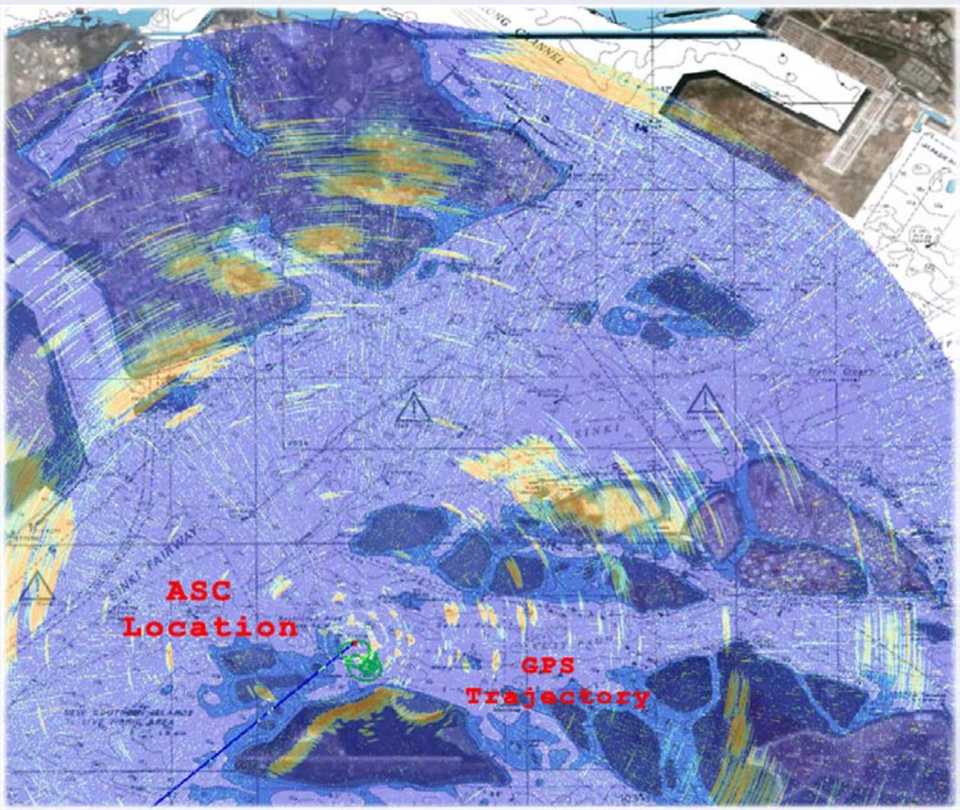
- Environmental monitoring of coastal waters.
- Navigation and map info. necessary above/below water surface.
- Fusion of sea surface radar, sub-sea sonar data for combined surface/sub-sea mapping.

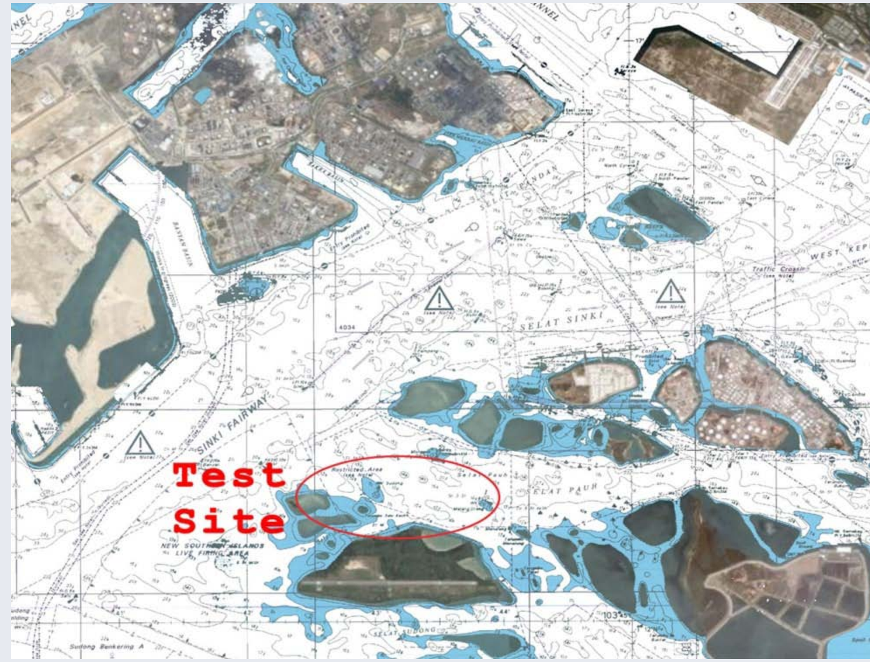


Autonomous Kayak Surface Vehicle with Radar

Singapore – MIT Alliance: CENSAM Project

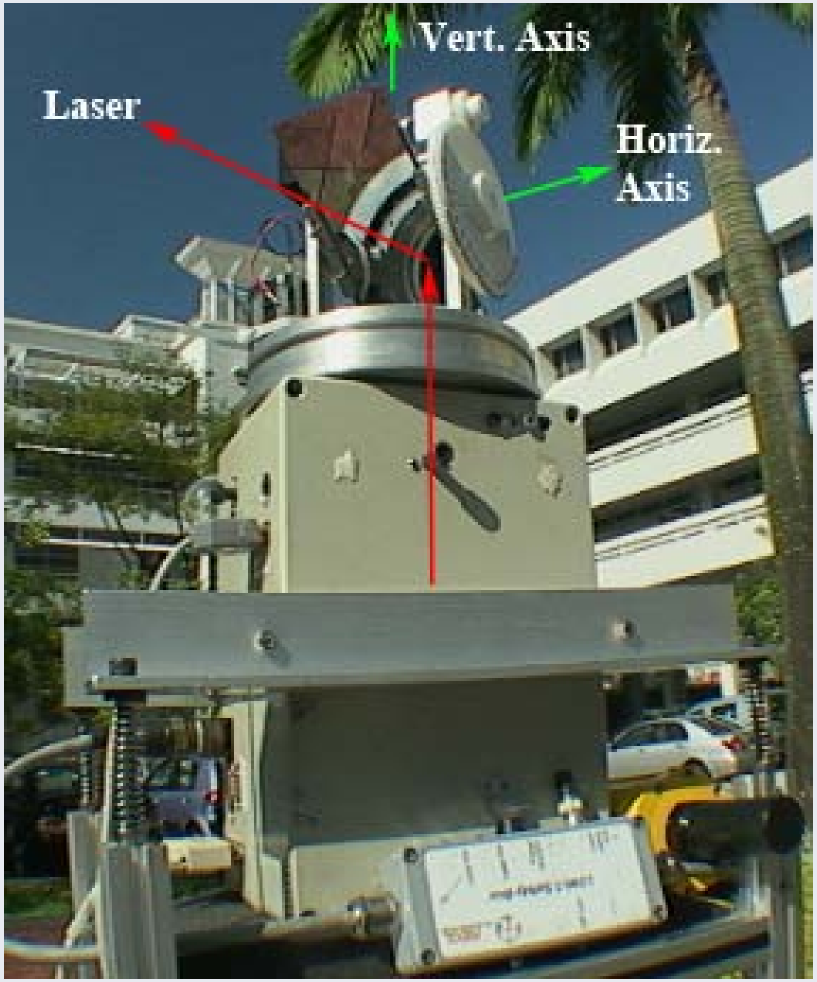
- Surface and sub-sea data.
- Verification of radar/sonar data with coastal satellite images.





A*Star: Fusing 3D LADAR & Vision [Sok, Adams 2009]

3D Laser Detection and Ranging



- Continuous 360 ° scanning unit.
- 200m max range.
- Time of Flight pulsed Riegl LADAR
- Accuracy (1 Sigma) 2cm.

A*Star: Fusing 3D LADAR & Vision [Sok, Adams 2009]

3D Laser Detection and Ranging

- 3D Point Cloud Data.
- Planar/Linear Segments visible.
- Data Compression with Principle Component Analysis (PCA).
- PCA unreliable on complete data sets.
- First Image Segmentation Necessary.

OpenGL2

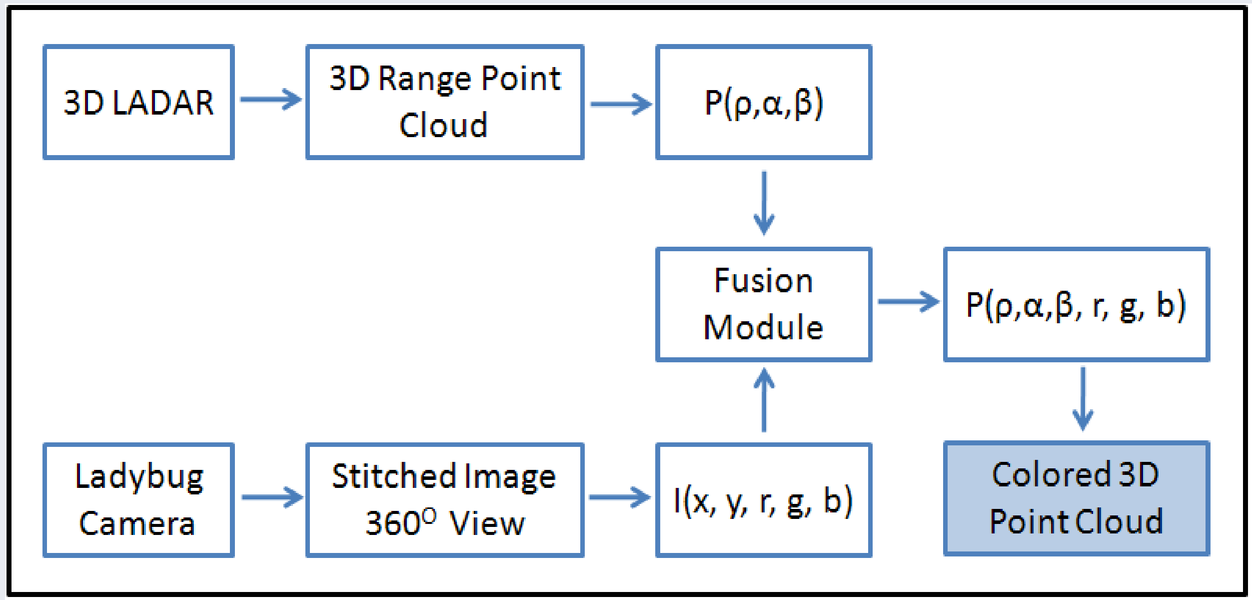
A*Star: Fusing 3D LADAR & Vision [Sok, Adams 2009]

Omni-Directional Vision

- Point Grey Lady Bug 2 – Panoramic camera.
- Approx. calibrate 3D LADAR data with image coords.
- Can be mounted coaxially with 3D LADAR.
- Stitch, Smooth and Segment Images
- Process 3D LADAR segments only.

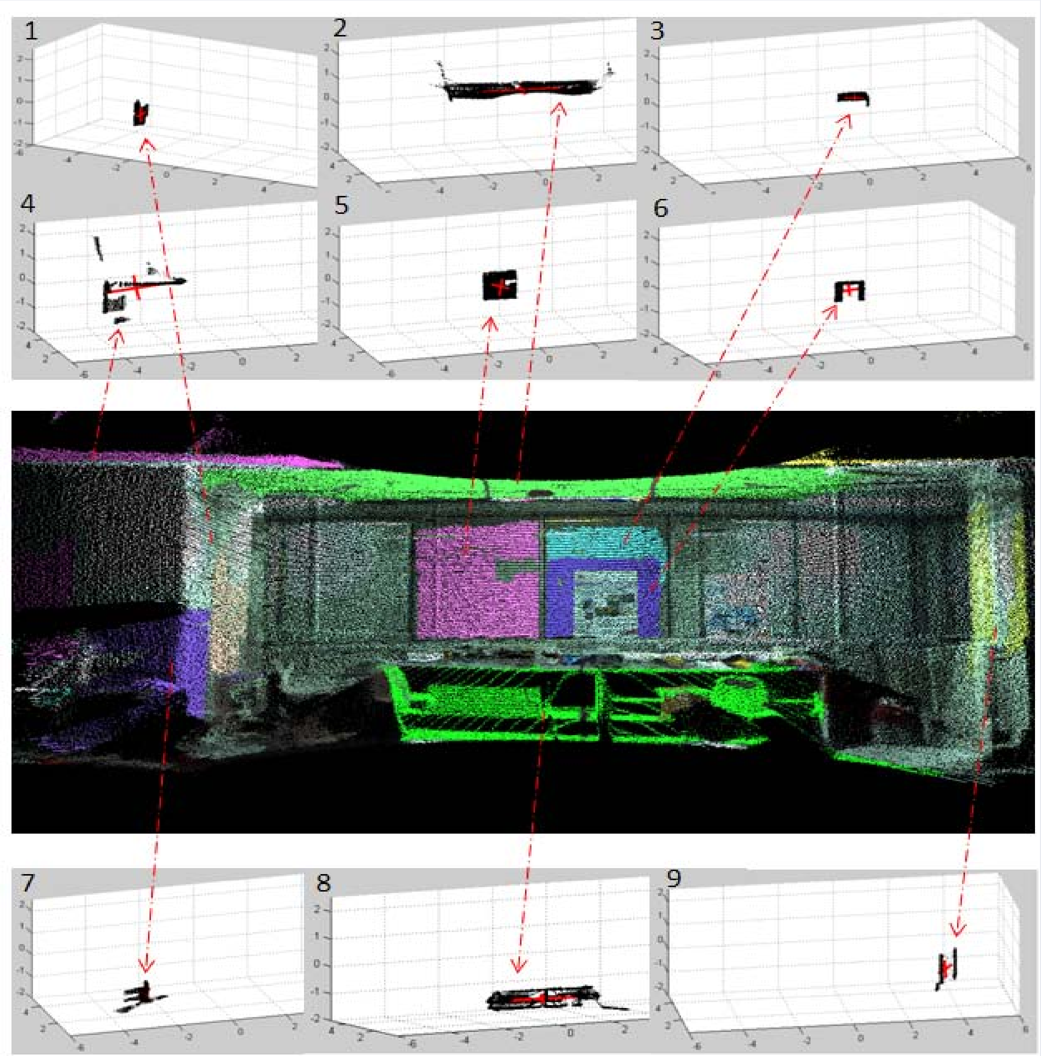
A*Star: Fusing 3D LADAR & Vision [Sok, Adams 2009]

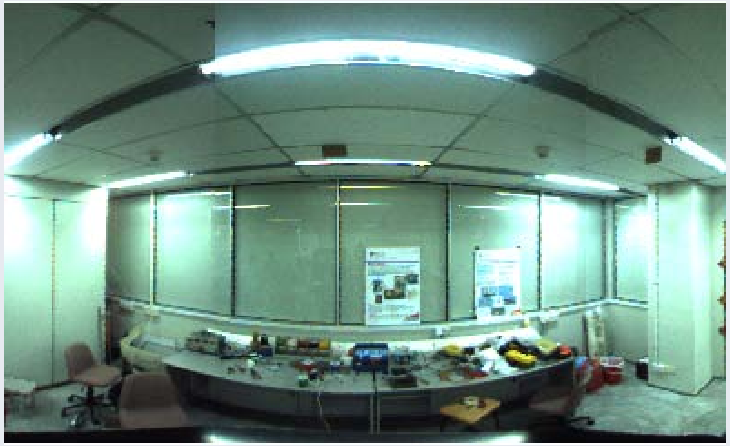
Approx. calibrate 3D ladar + camera data -> Coloured 3D point cloud.



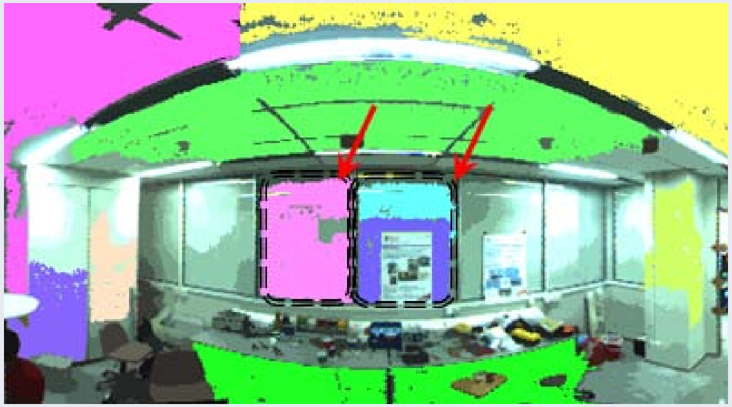
OpenGL2

PCA: Dominant Data Directions, Extracted Planes





Section of Original Image



Segmented Image

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SLAM Fundamentals

- In an unknown environment – robot & feature positions *must* be estimated simultaneously – SLAM.

- SLAM is a probabilistic algorithm

$$p(x_t, m \mid z_{1:t}, u_{1:t})$$

$$x_t = \text{State of the robot at time } t$$

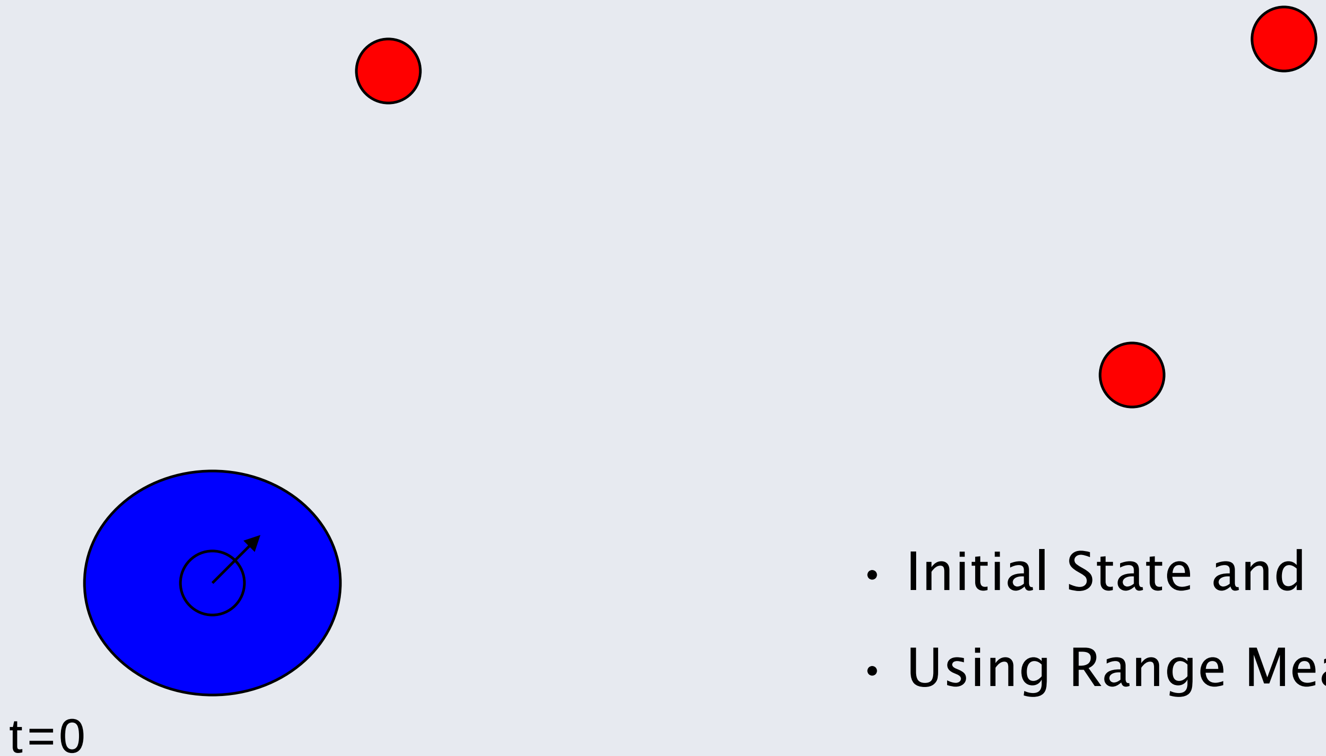
$$m = \text{ Map of the environment}$$

$$z_{1:t} = \text{ Sensor inputs from time 1 to } t$$

$$u_{1:t} = \text{ Control inputs from time 1 to } t$$

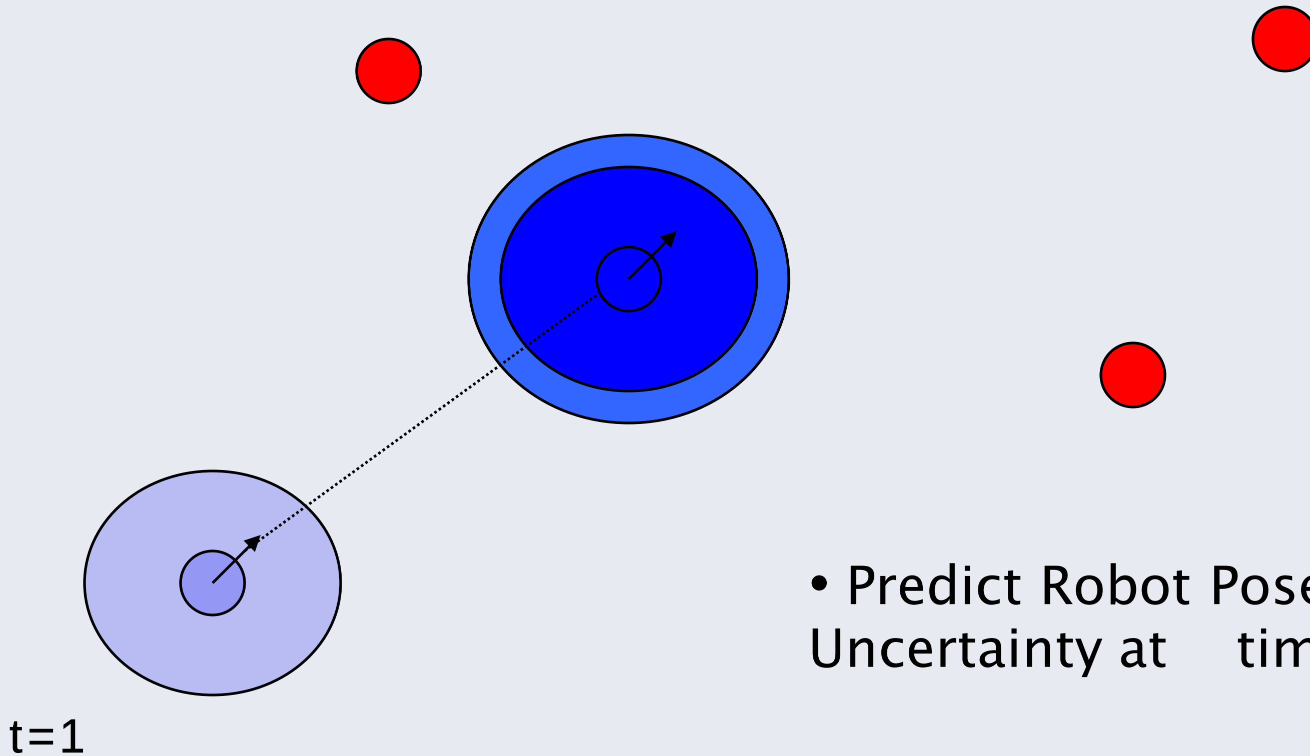
- Update distribution estimate with Bayes theorem.

SLAM Fundamentals



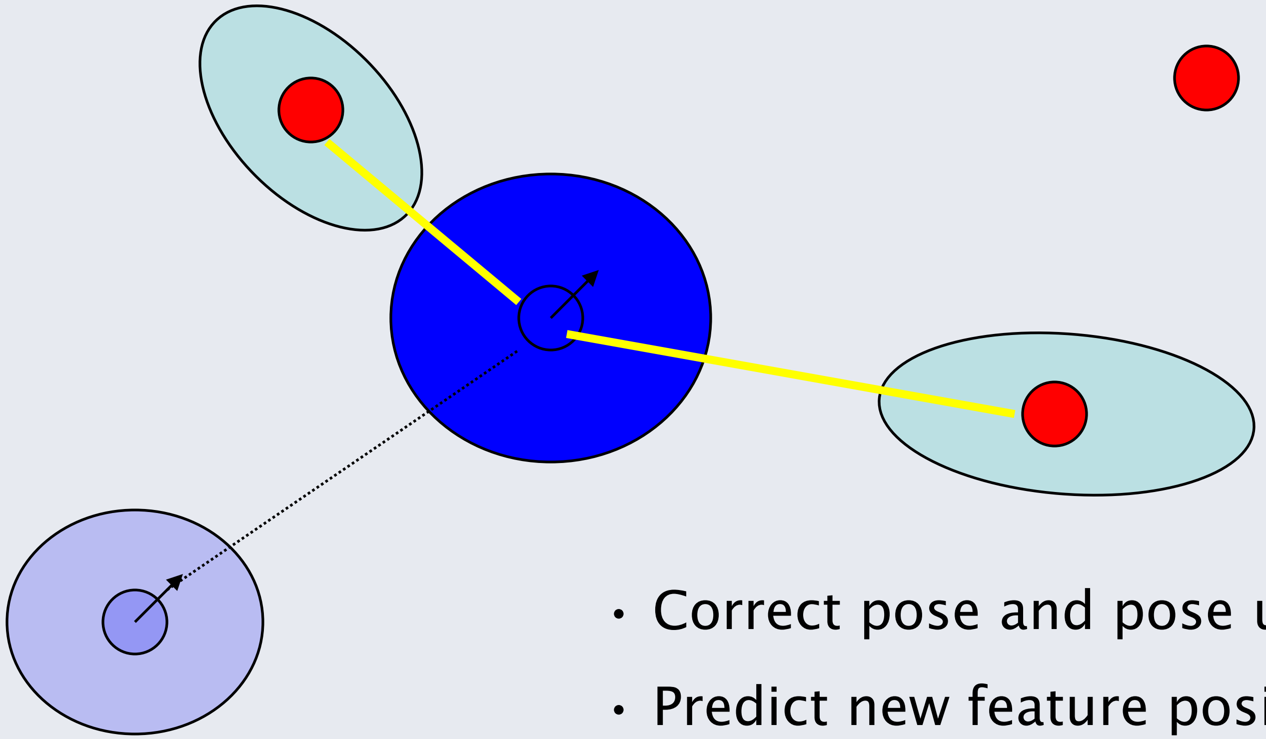
- Initial State and Uncertainty
- Using Range Measurements

SLAM Fundamentals



- Predict Robot Pose and Uncertainty at time 1

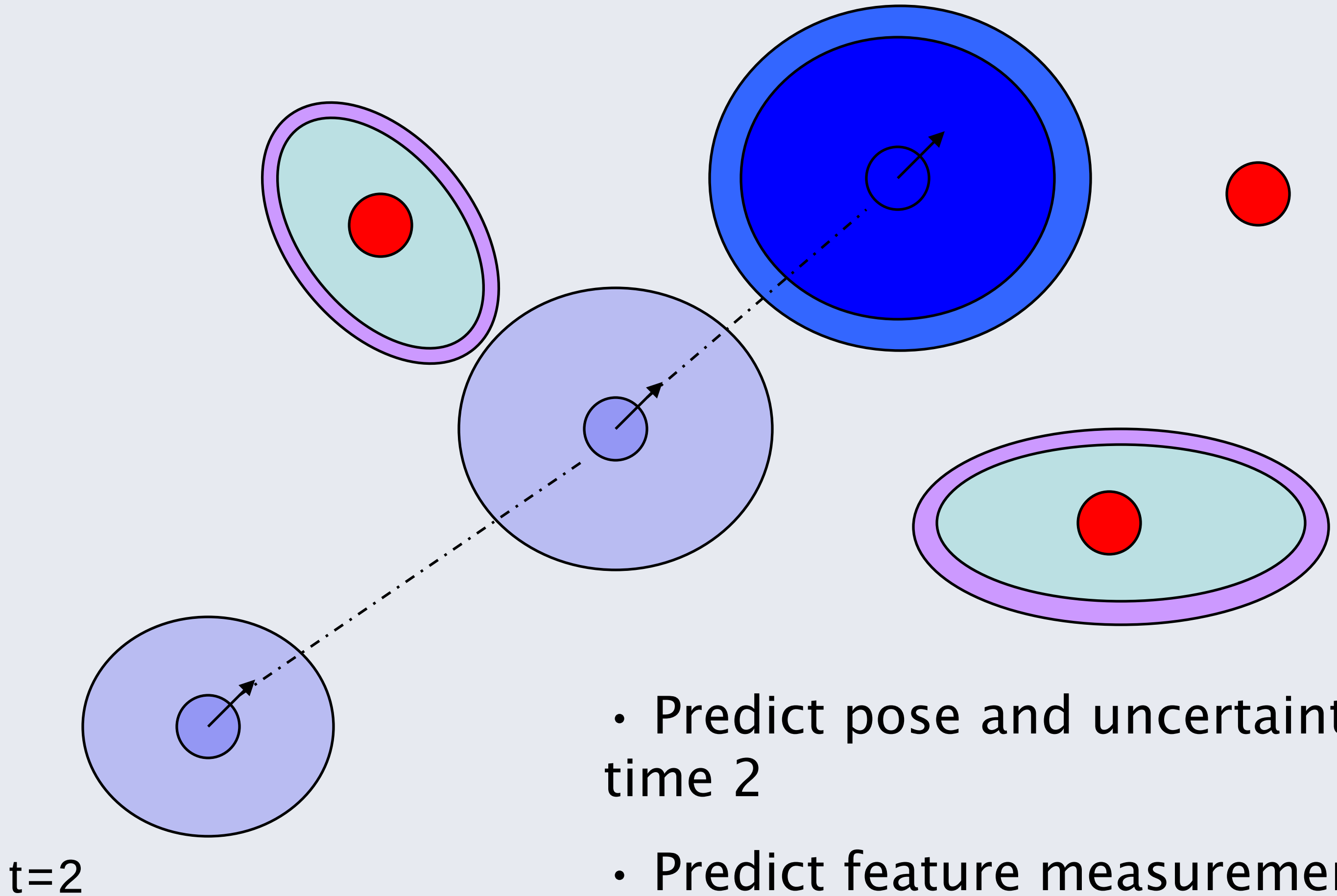
SLAM Fundamentals



t=1

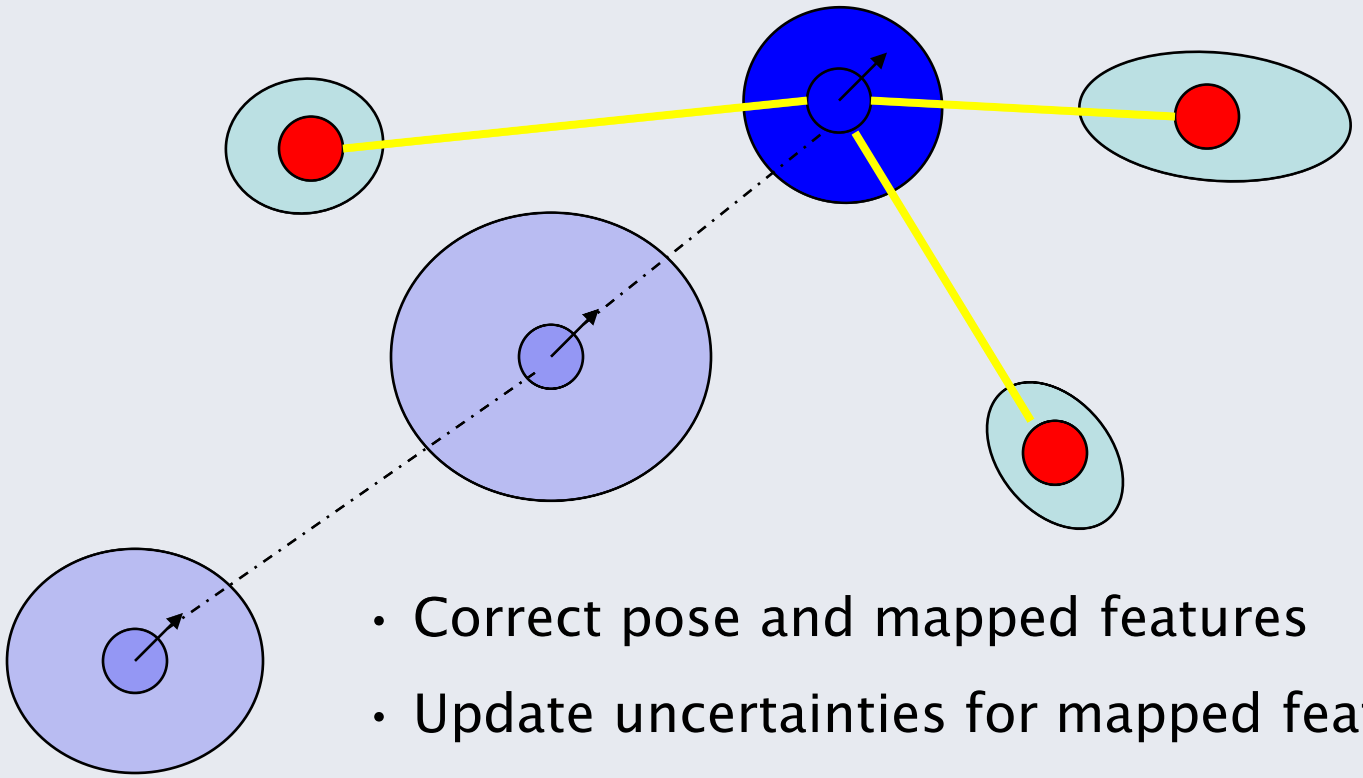
- Correct pose and pose uncertainty
- Predict new feature positions and their uncertainties

SLAM Fundamentals



- Predict pose and uncertainty of pose at time 2
- Predict feature measurements and their uncertainties

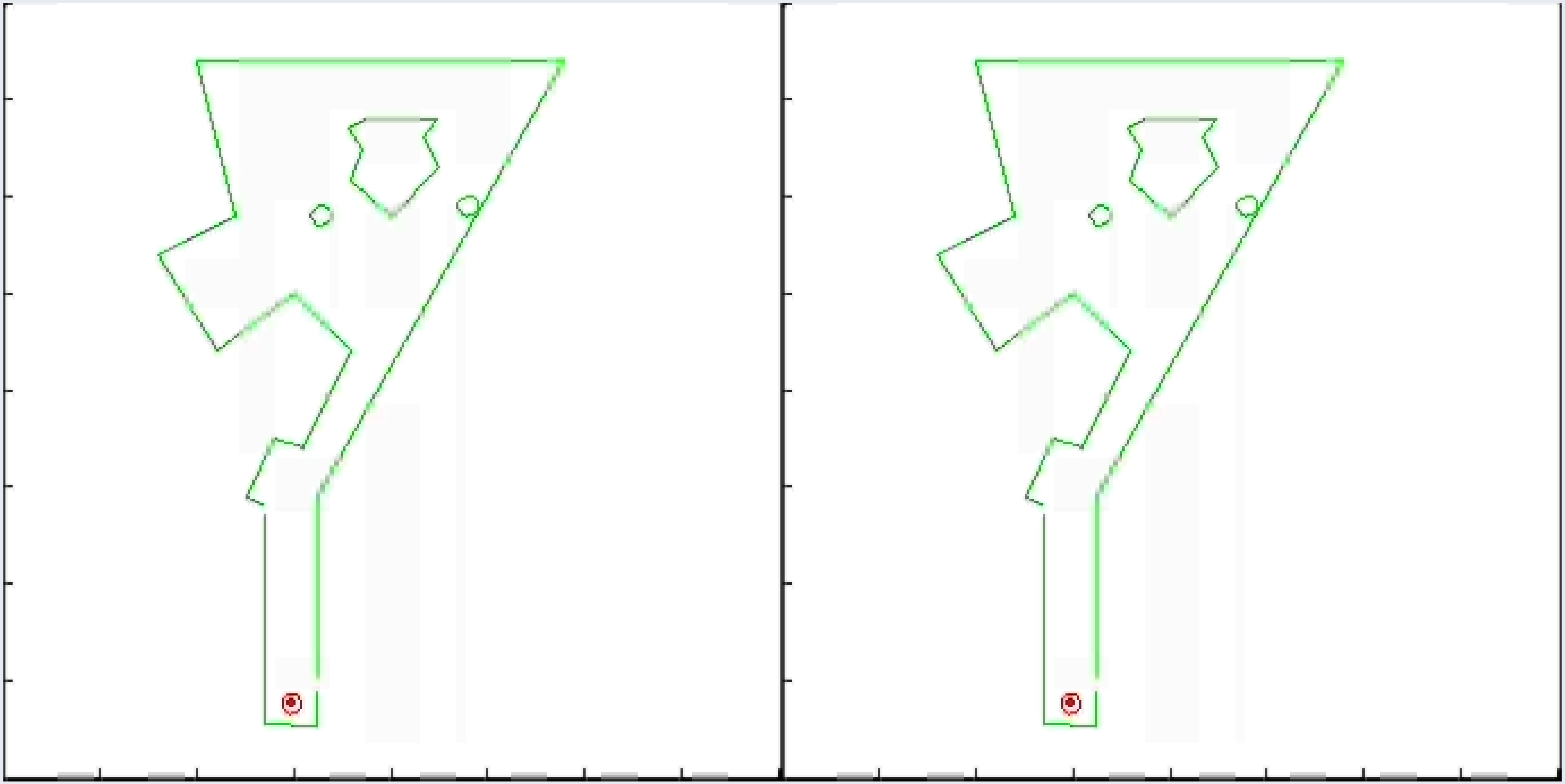
SLAM Fundamentals



- Correct pose and mapped features
- Update uncertainties for mapped features
- Estimate uncertainty of new features

t=2

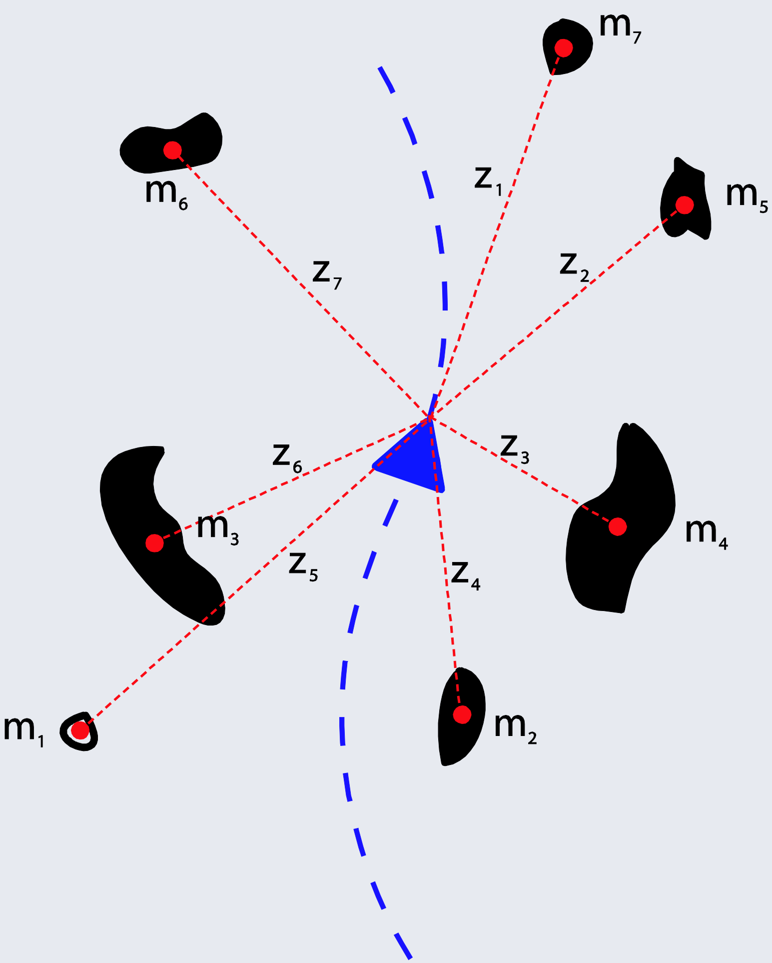
SLAM: A Real Experiment



SLAM using line intersection features in 80m by 35m office corridors.

Vid 4, Vid 5

Difficulties of SLAM – Data Association



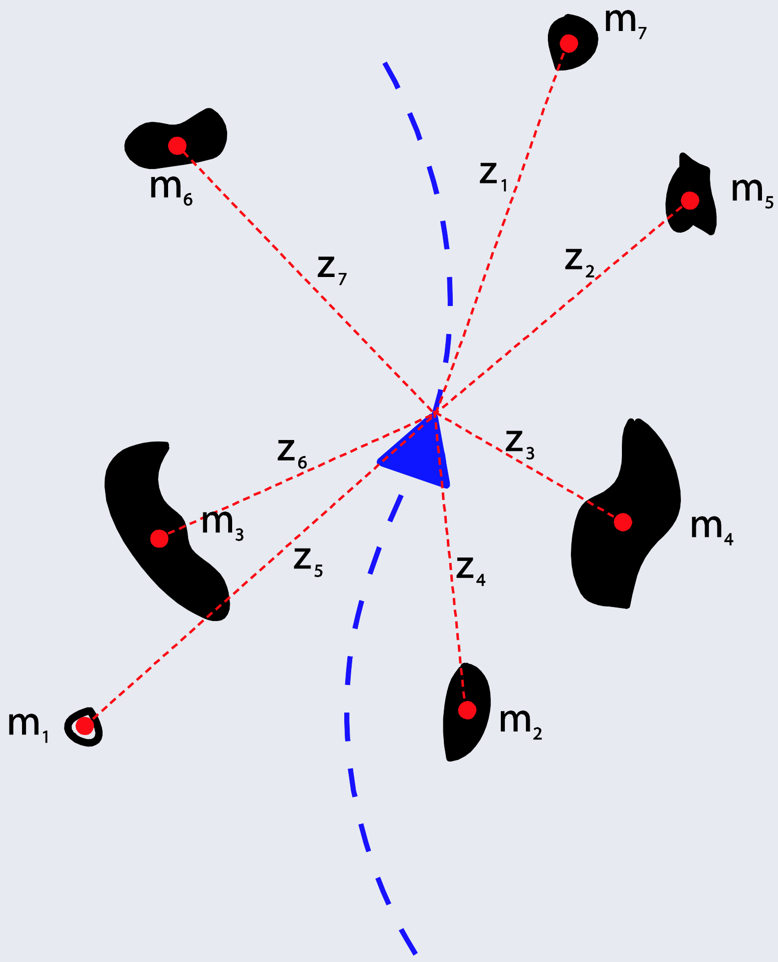
Untangle:

$$\mathbf{Z} = [\mathbf{z}_1, \mathbf{z}_2, \mathbf{z}_3, \mathbf{z}_4, \mathbf{z}_5, \mathbf{z}_6, \mathbf{z}_7]$$

?

$$\mathbf{M} = [\mathbf{m}_1, \mathbf{m}_2, \mathbf{m}_3, \mathbf{m}_4, \mathbf{m}_5, \mathbf{m}_6, \mathbf{m}_7]$$

Difficulties of SLAM – Data Association

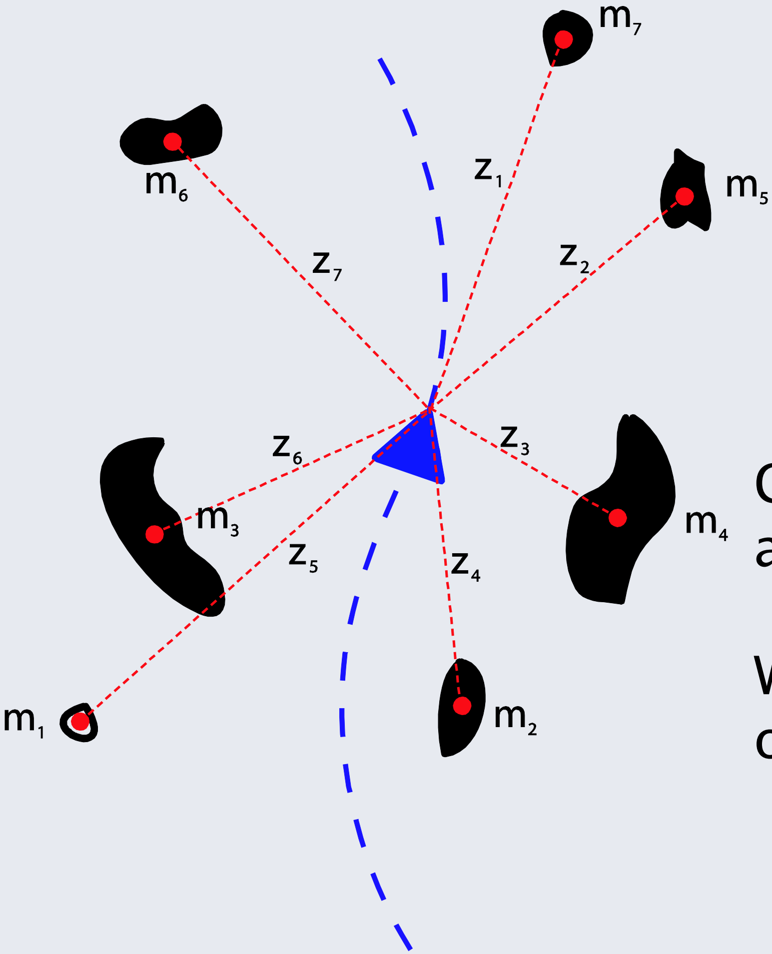


Untangle:

$$Z = [z_1, z_2, z_3, z_4, z_5, z_6, z_7]$$

$$M = [m_1, m_2, m_3, m_4, m_5, m_6, m_7]$$

Difficulties of SLAM – Data Association



Untangle:

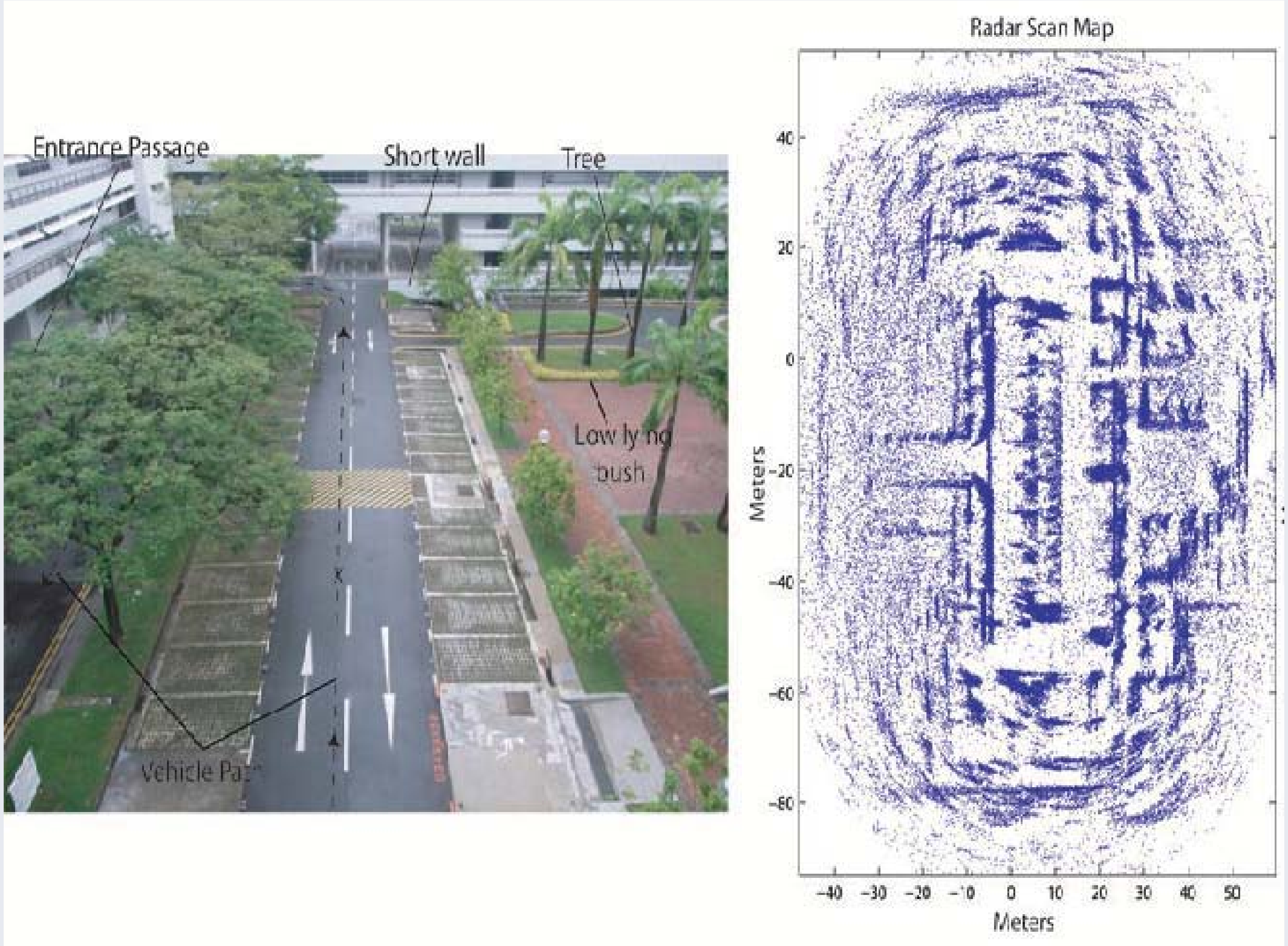
$$\mathbf{Z} = [\mathbf{z}_1, \mathbf{z}_2, \mathbf{z}_3, \mathbf{z}_4, \mathbf{z}_5, \mathbf{z}_6, \mathbf{z}_7]$$

$$\mathbf{M} = [\mathbf{m}_1, \mathbf{m}_2, \mathbf{m}_3, \mathbf{m}_4, \mathbf{m}_5, \mathbf{m}_6, \mathbf{m}_7]$$

Current vector formulations *require* data association (DA) prior to Bayesian update:

Why? Features & measurements rigidly ordered in vector-valued map state.

Difficulties of SLAM – Data Association

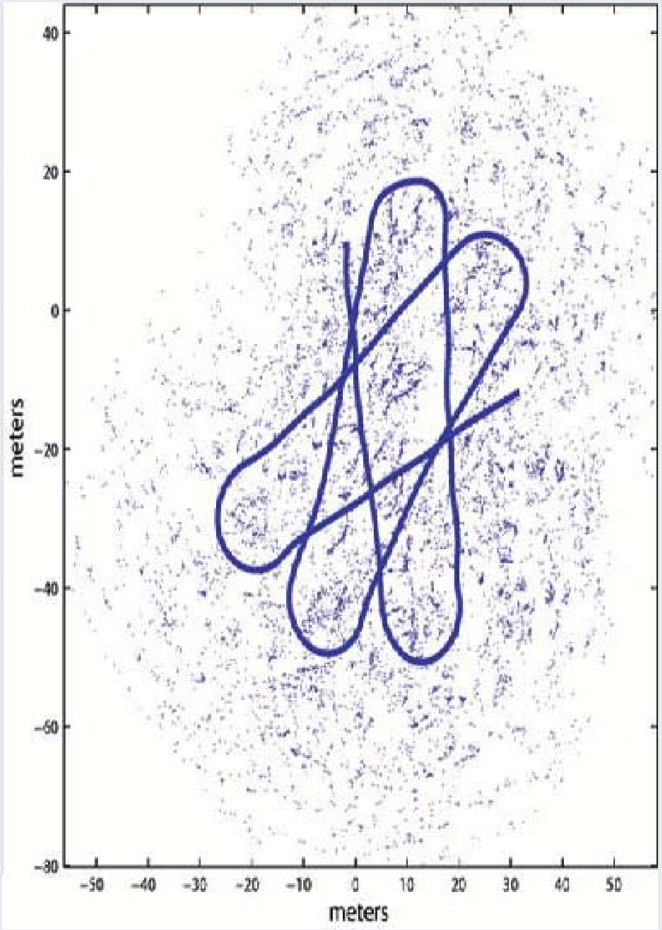


Sample data registered from radar.

Vid 1

Difficulties of SLAM – Data Association

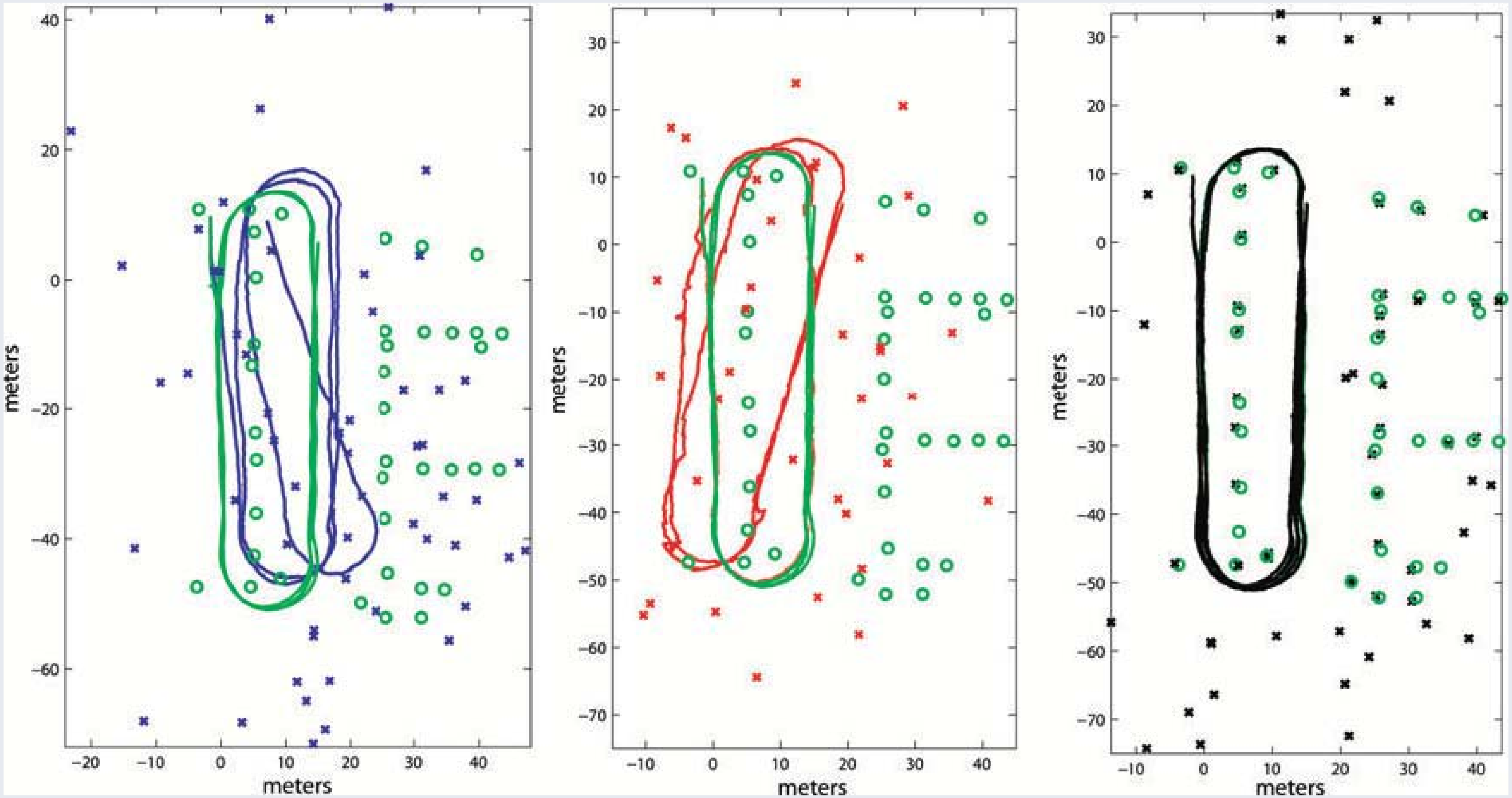
SLAM input: Odometry path + radar data



Extracted point feature measurements registered to odometry.

Difficulties of SLAM – Data Association

NN-EKF FastSLAM PHD-SLAM



EKF, FastSLAM and PHD-SLAM with Radar data.

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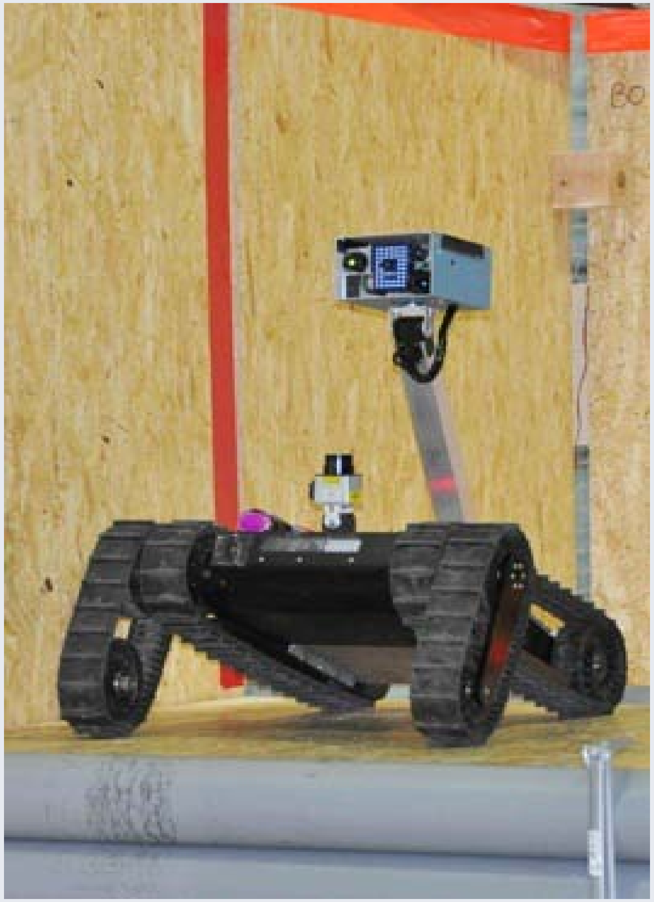
Mechatronic Autonomy in Mines/Rugged Terrains

- Caterpillar: “CAT Integrated Object Detection” Fusion of radar/vision for object detection [Australian Mining, 2009].
  - Rio Tinto + ACFR developing autonomous mining technologies [Durrant-Whyte 2007].
  - Codelco developing unmanned haulage system “FrontRunner” at Gaby copper mine, Chile [Komatsu 2007].

- Acumine: Millimetre Wave Radar in Surface Mining [Brooker 2006].

Sensing & Mechatronics for Search & Rescue

Thredbo Landslide:
Mechatronic Search & Rescue Aids called for [ABC News].



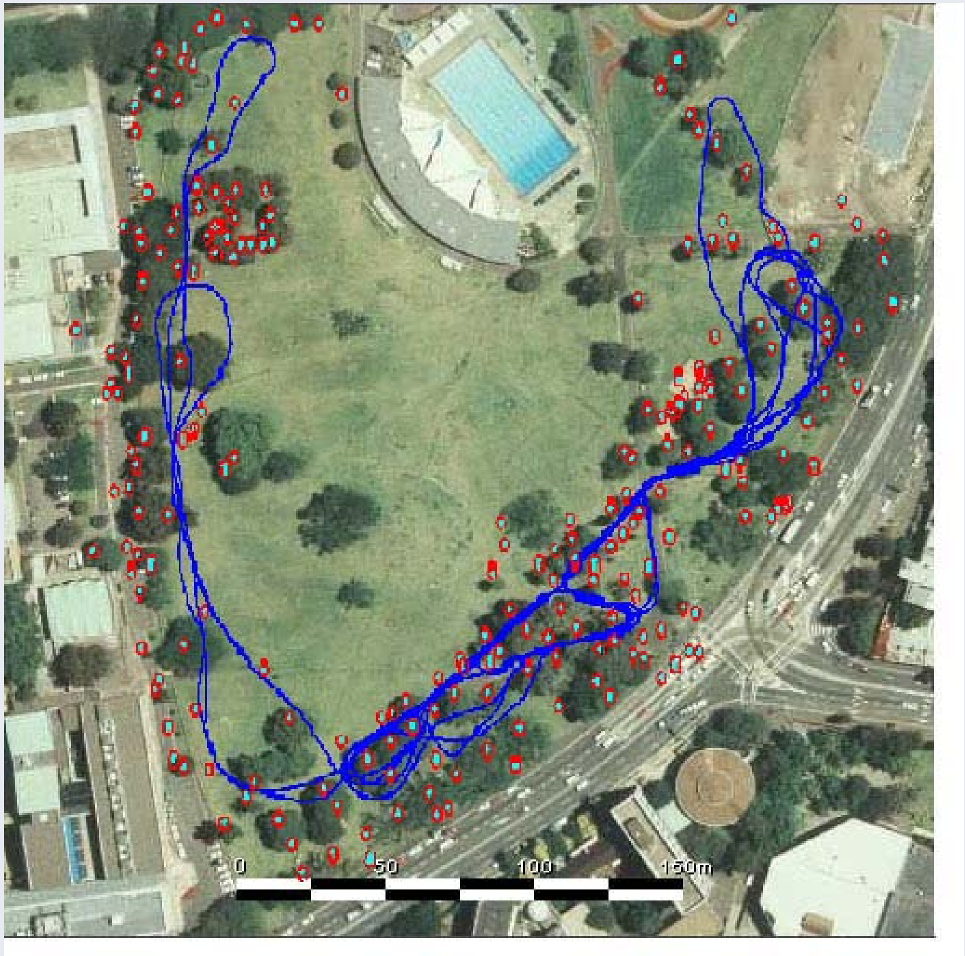
Rescue Robotics – Challenges:
Mechanical Design & Traction,
Obtsacle Avoidance,
Victim Detection,
Localisation & Path Planning.

(UTS USAR Vehicle [Valls Miro, Gamini 2009].)

Navigation in Complex Environments

Navigation in the presence of clutter.

…on land.



Victoria Park Data Set
[ACFR, University Sydney].

Navigation in Complex Environments

Australian Institute of Marine Science & ACFR: AUV “Sirius” for underwater monitoring. [Stefan Williams 2007].

BHP Billiton: Sponsors Trials At Ningaloo Reef for testing suitability of robots for reef monitoring. [Stefan Williams 2007].

Navigation in Complex Environments

Australian Institute of Marine Science & ACFR: AUV “Sirius” for underwater monitoring. [Stefan Williams 2007].

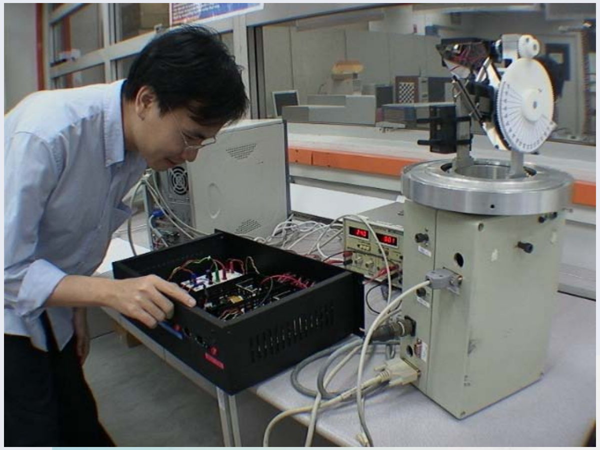
Successful sensing & navigation required in environments with complex feature representations, disturbed by clutter.

BHP Billiton: Sponsors Trials At Ningaloo Reef for testing suitability of robots for reef monitoring. [Stefan Williams 2007].

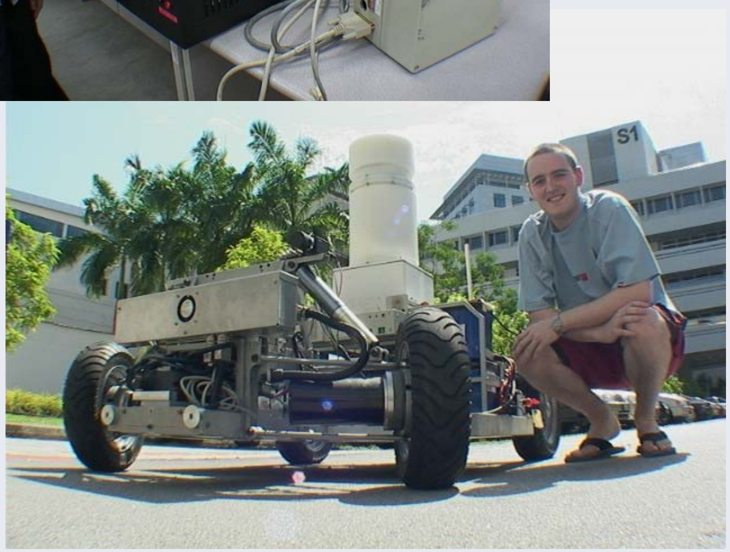
Motivation for Robotics & Autonomous Systems

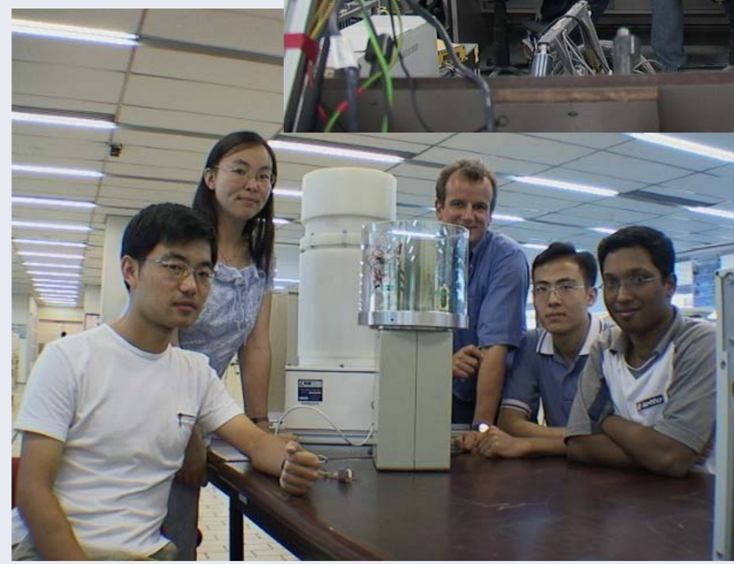
1. Improve robustness of autonomous sensing systems.
2. Radar for pedestrian/traffic monitoring in ITS.
   Improve traffic safety through sensor technologies.
3. Surface & sub-sea joint environmental/navigation estimation.
4. Extend 3D sensor fusion technologies in scene inspection & security research – Application in mining.
5. Probabilistic sensor modelling – improve robustness to sensor bias, random walk, clutter, false alarms and missed detections.
6. Improve fundamental aspects of SLAM – Random Finite Set (RFS) rather than vector based map representations.

Thank You & Acknowledgements



The Research Team:





John Mullane, Ba-Ngu Vo, Jonathon Chee Weng, Chhay Sok, Liu Bingbing, Ebi Jose, Tang Fan, Lochana Perera, Zhang Sen, Zen Koh, Bimas Winaju, Andy Shacklock, Akshay Rao, Tan Chai Soon ………..!

Thank You!