

Navigating an outdoor robot with simple discontinuous landmarks

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Piloting

a navigation strategy that uses known landmarks

landmark

- feature in the environment
- used sequentially to find the way to the goal
- position can be sensed
- close to the desired path
- direction varies significantly as you move along the path

navigator

- familiar with the area
- know which landmarks to look for

Puluwat Atoll navigators

- planing - imagine the position of destination relative to the position of other islands
- sailing - constantly adjusts direction according to his awareness of his current position
- decisions - improvised continually by checking relative positions of landmarks

Visual Flight Rules

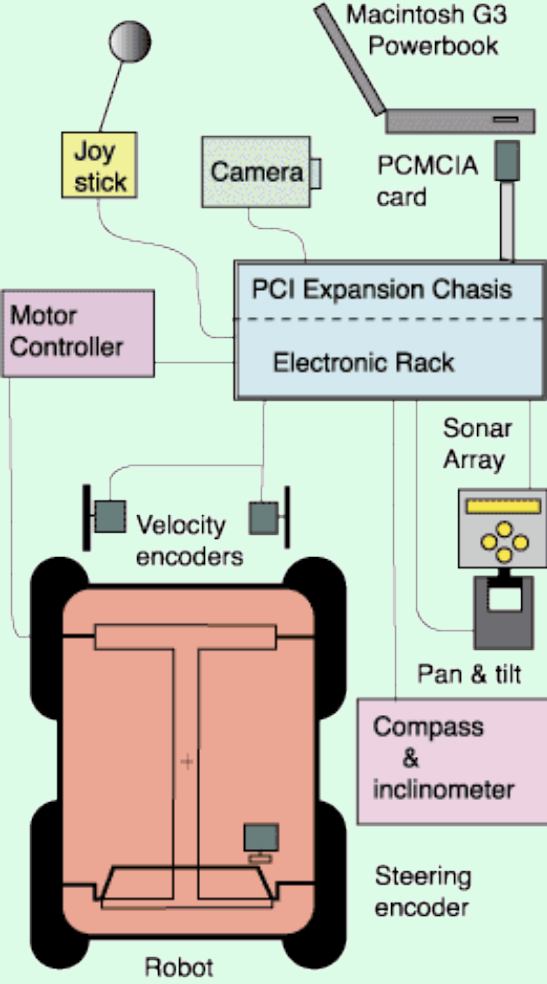
- for flying a light aircraft across country
- planing
- pilot chooses a sequence of legs between landmarks from an aviation map
- calculates the length and magnetic bearing of each leg
- flying
- flies along the first leg to the location where he expects to find the first landmark
- decisions
- slows down to scan the area looking for the landmark
- estimates the error in his location from landmark
- re-plans the next leg
- repeats this process until he reaches his destination

Titan Outdoor Robot

sensing a pole in a field with a CTFM phased array ultrasonic sensor



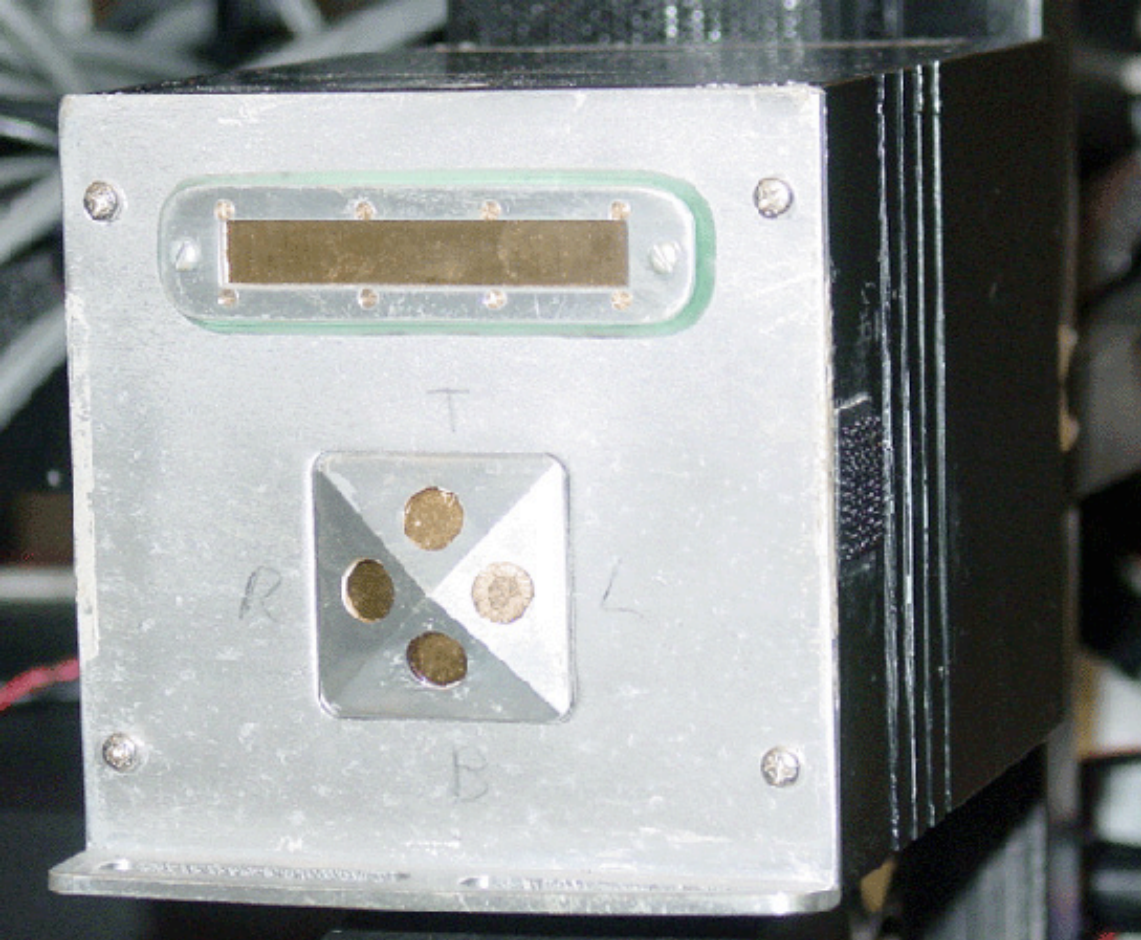
Block Diagram



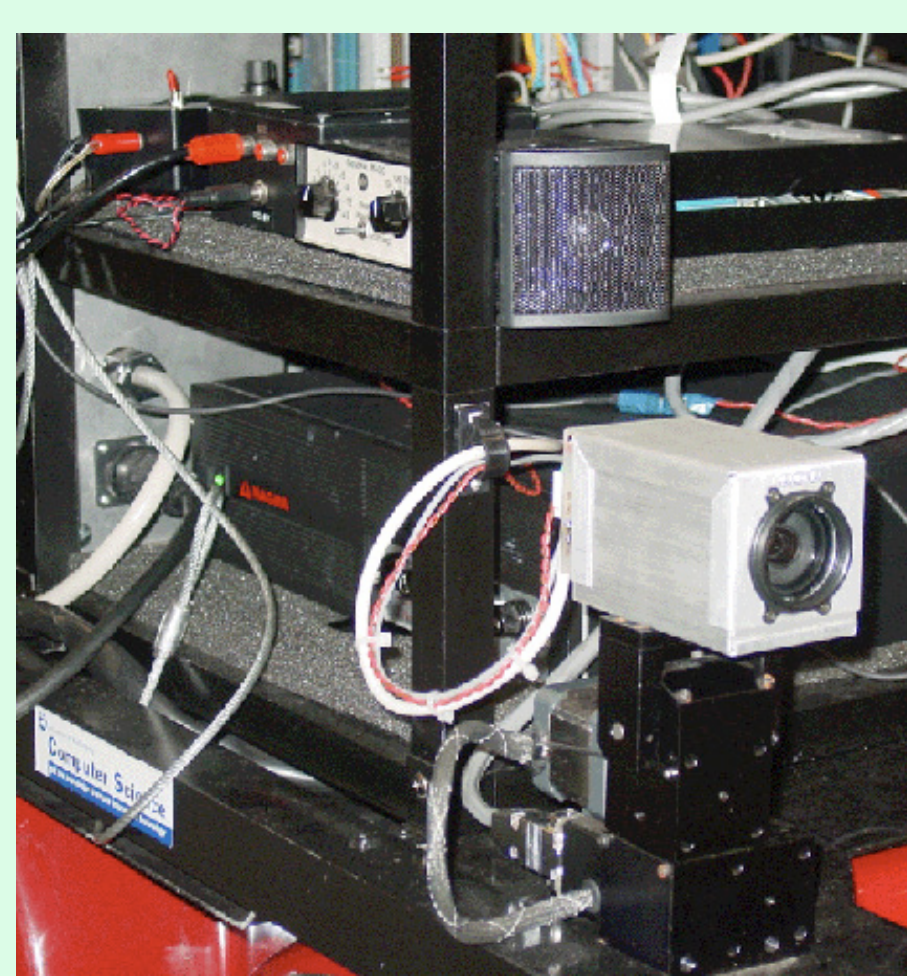
Velocity and Distance encoder



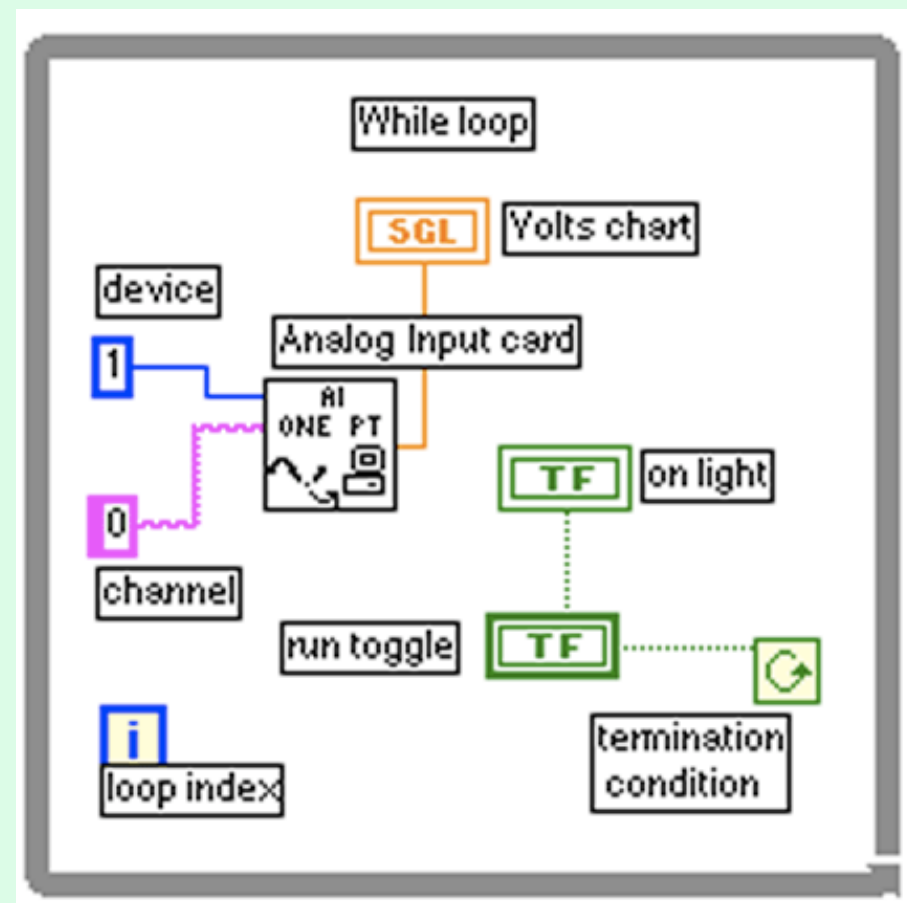
Ultrasonic phased array



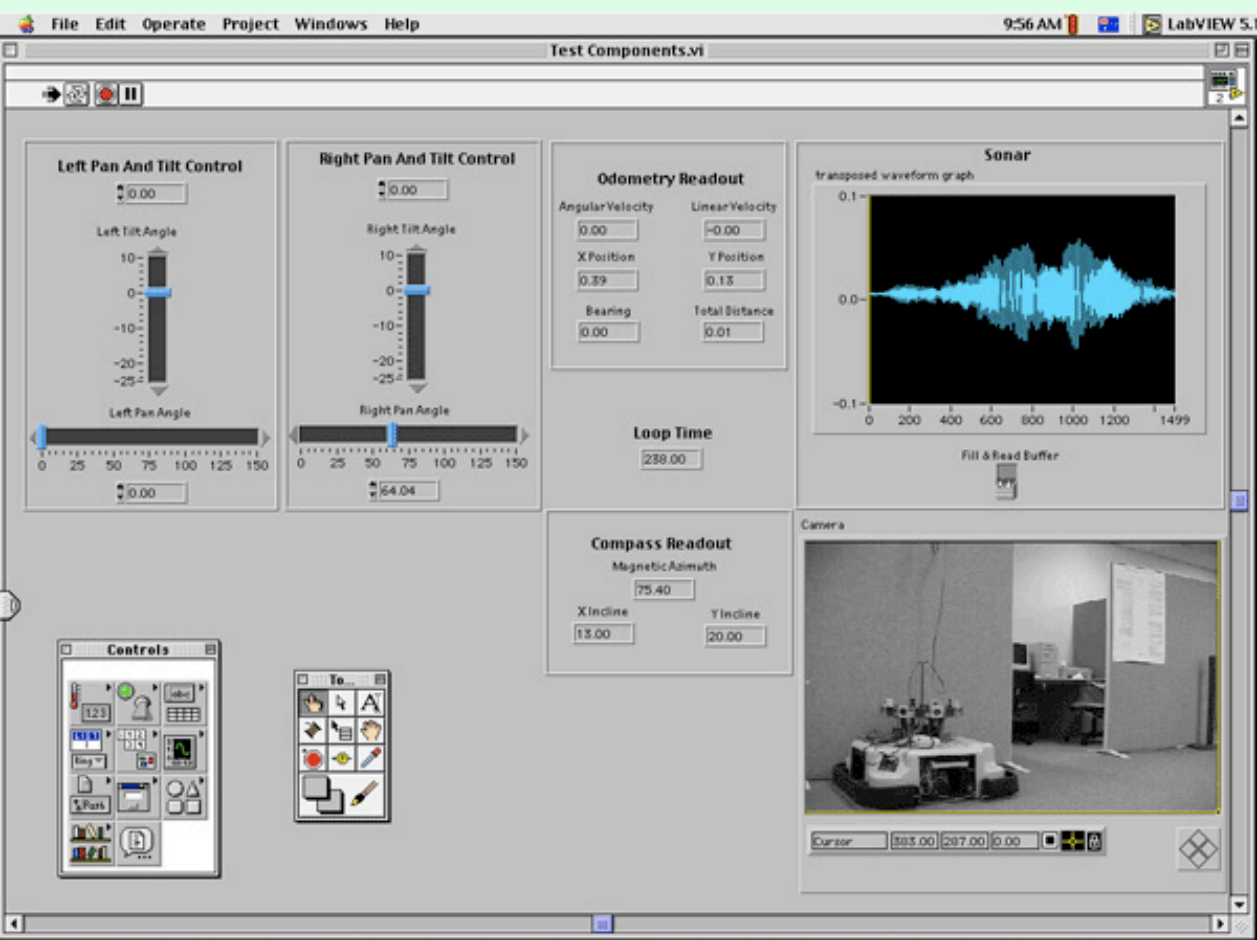
Vision and electronics



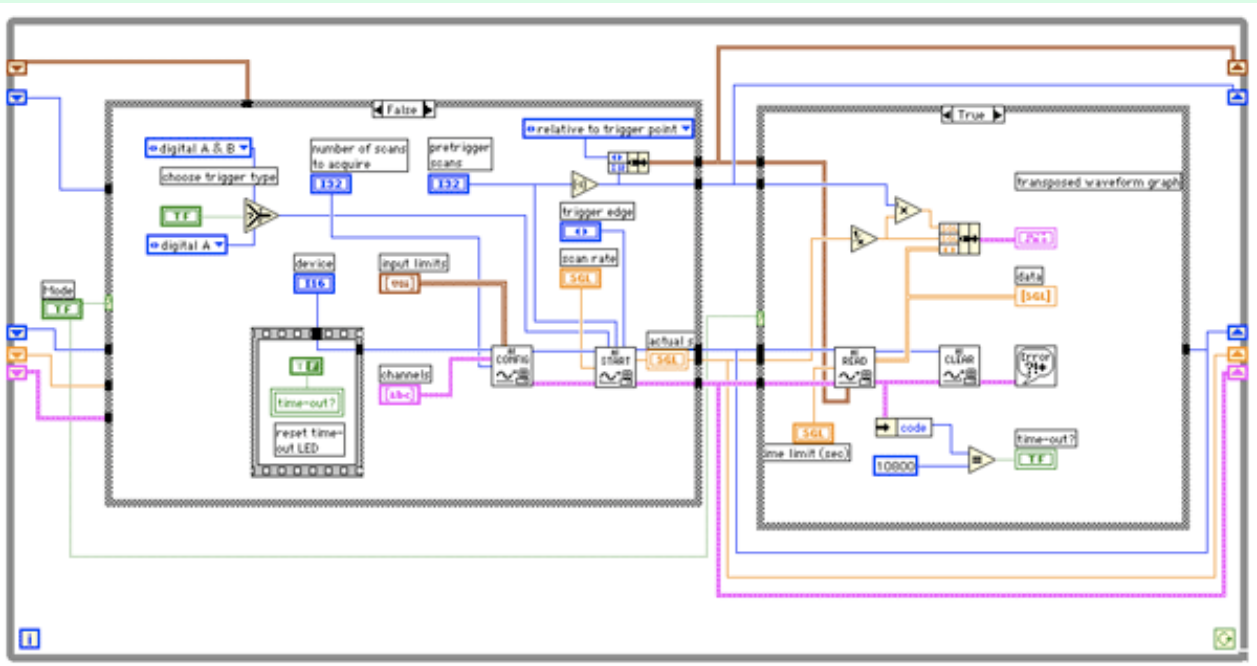
LabView - OO graphical language for soft real-time data acquisition and control



Test panel built with I/O library



Ultrasonic echo capture program from library

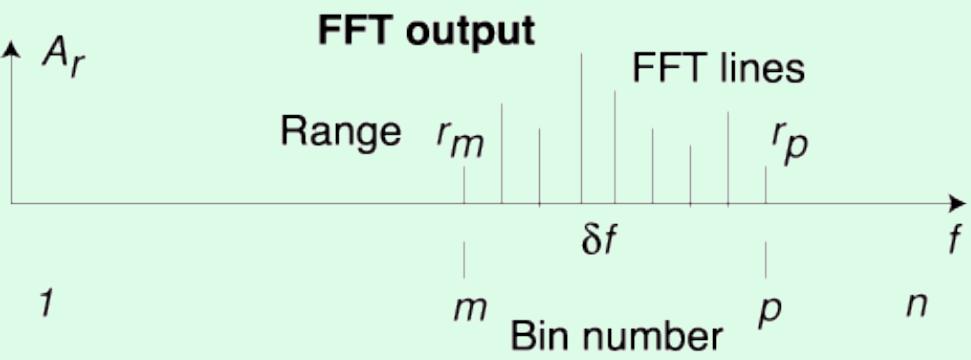
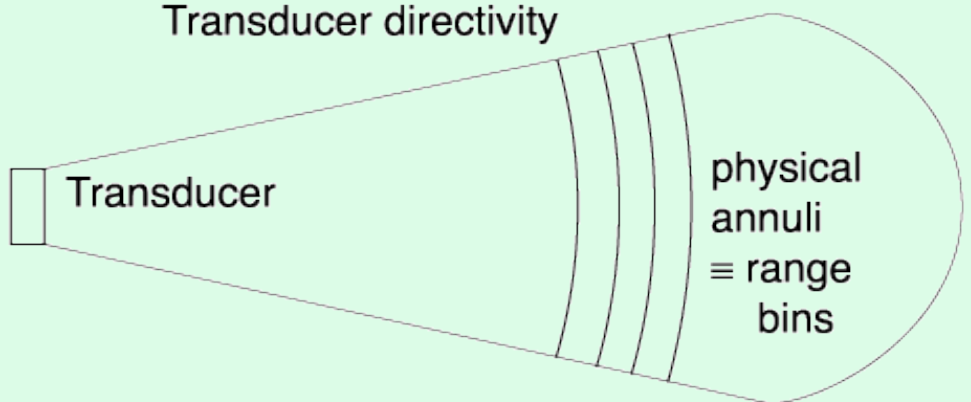


CTFM Ultrasonic Sensing

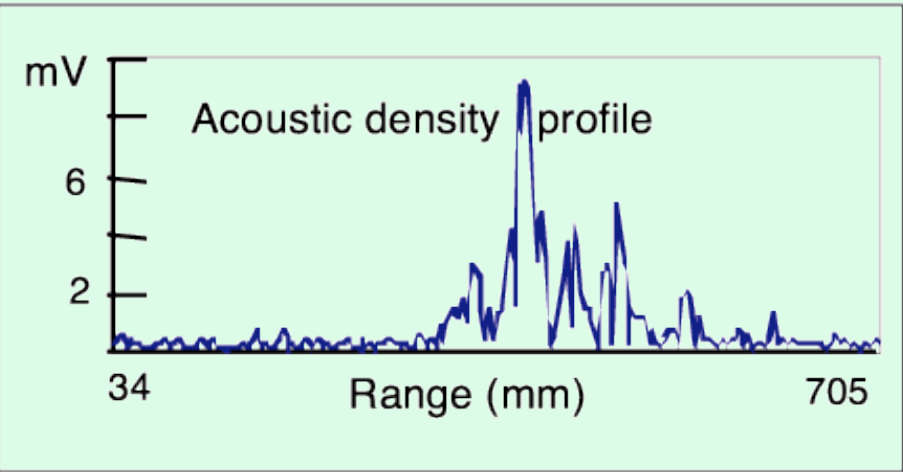
Mobility aid for blind people



Acoustic density profile model



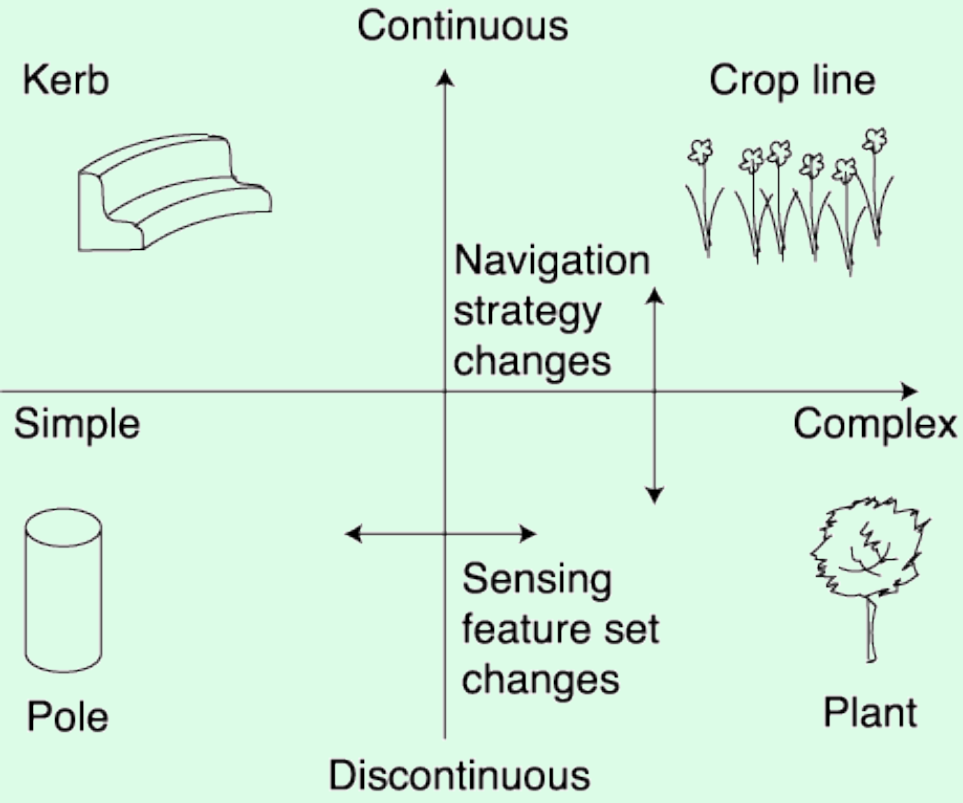
Acoustic density profile of a plant



Sensing [plants](#)

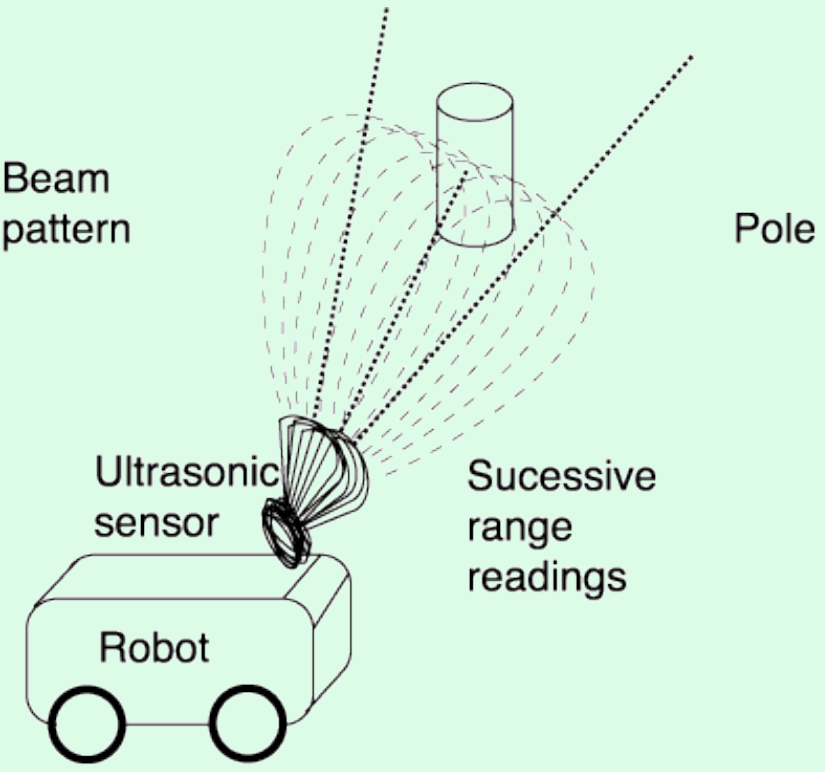
Sensing landmarks

Landmark types

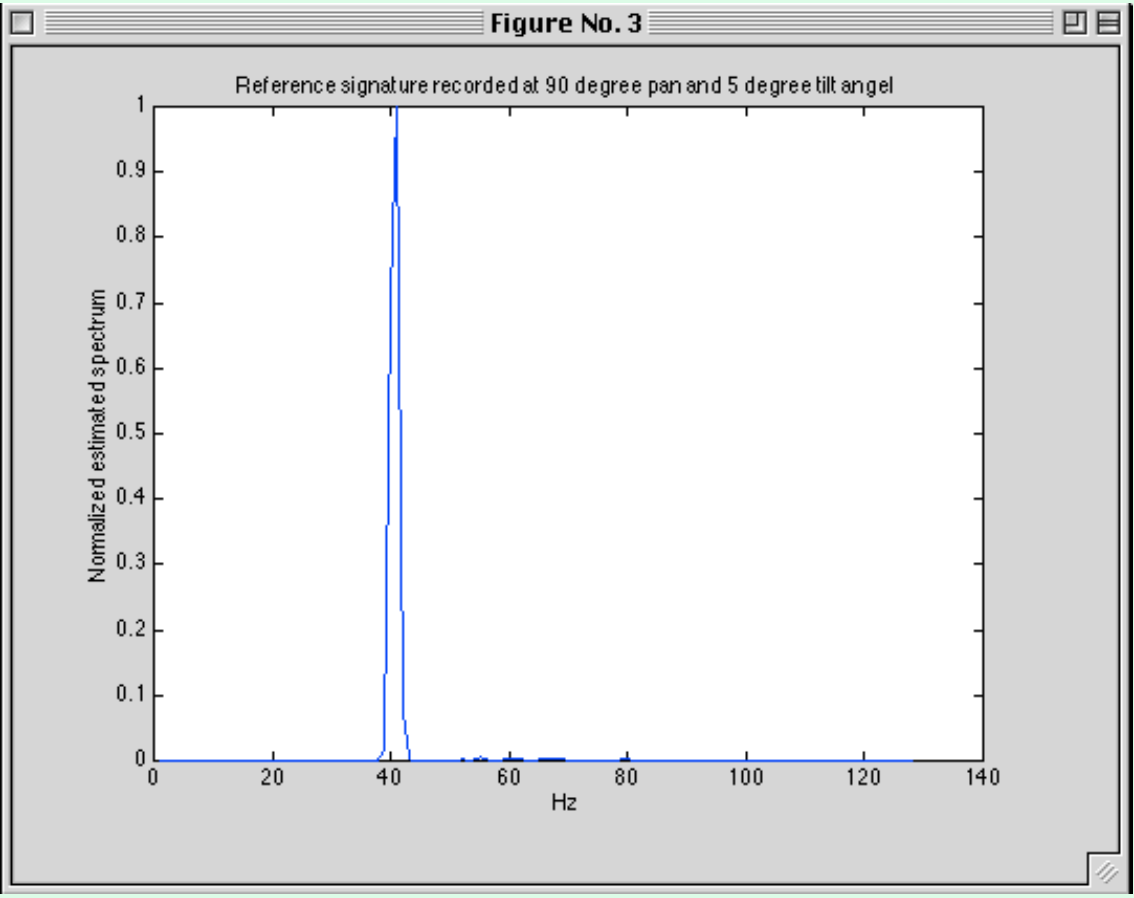


Following a [continuous](#) landmark

Sensing strategy for a discontinuous landmark - scanning across a pole

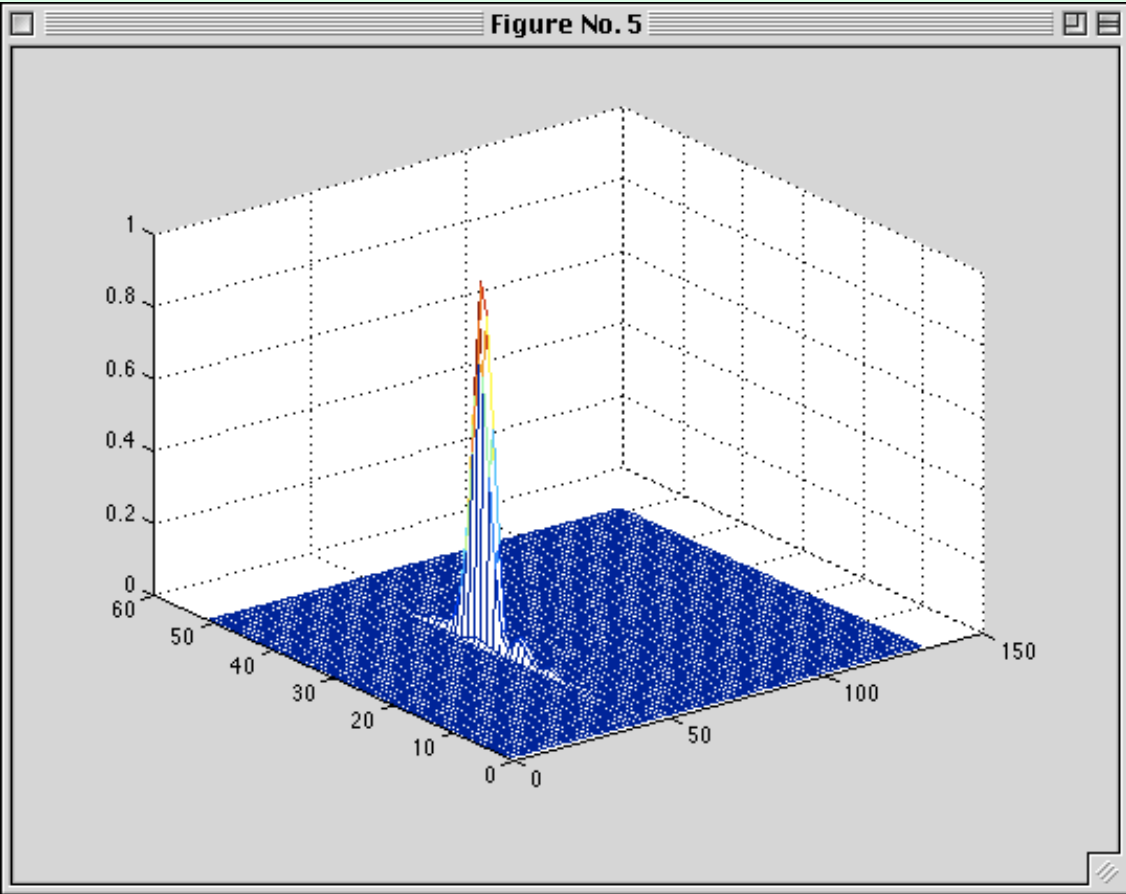


Normalised acoustic density profile of a pole

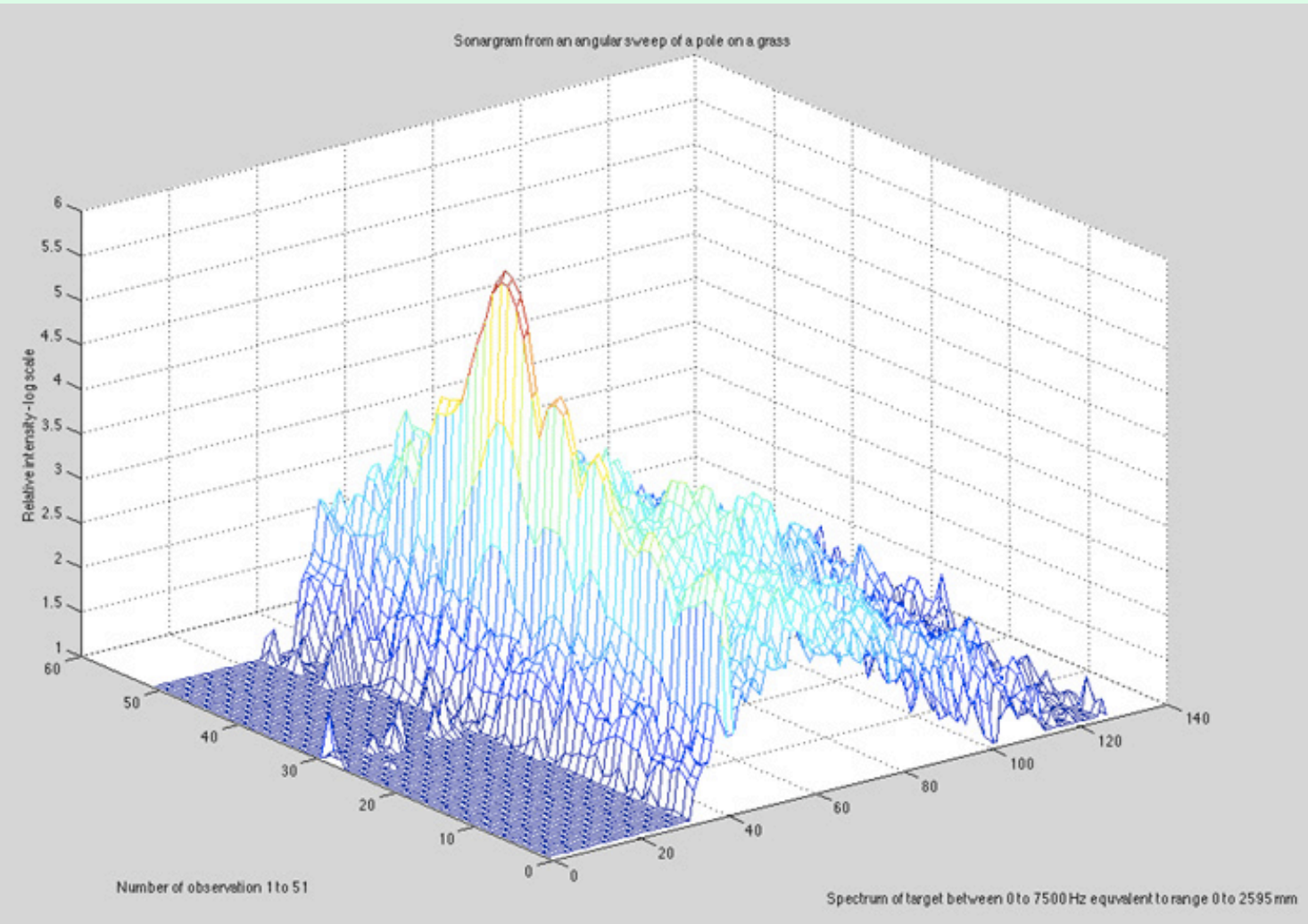


Linear sonogram of a 50 mm aluminium pole in 1° steps

Figure No. 5



Log sonogram of scan across pole



Landmark Navigation

Visual flight rules strategy

5. LANDMARK NAVIGATION MAP

- straight legs between landmarks.
- a small radius turn from one bearing to the next at landmark

Aircraft

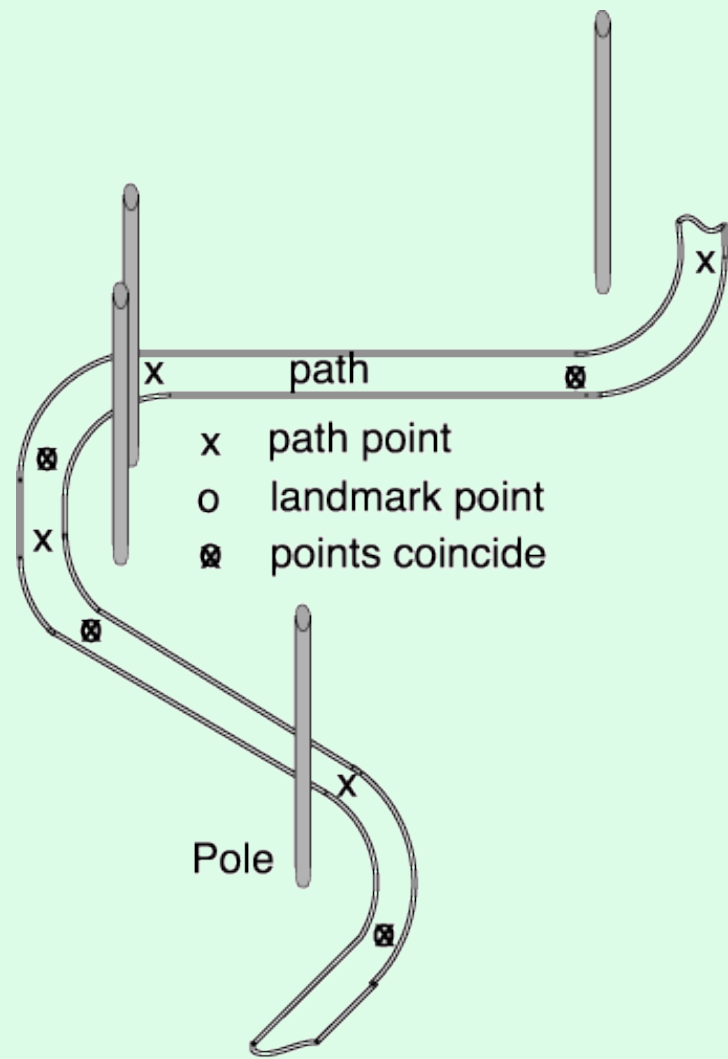
distance between landmarks is usually much larger than the distance around a turn - sharp turns

Mobile robot

- sharp turns in some applications - moving across an open field
- applications where the length of curved legs is similar to the length of the straight legs

Landmark map

- The course to be travelled by the robot is a path
- A *path* is a sequence of legs
- a *leg* is a path between two points
 - end point of one leg is the start point of the subsequent leg.
 - can be straight or a section of an arc.
- *Landmark point* - the location of the robot at the time when it should sense the landmark.



x path point
 o landmark point
 ☒ points coincide

Pole

Teaching a path

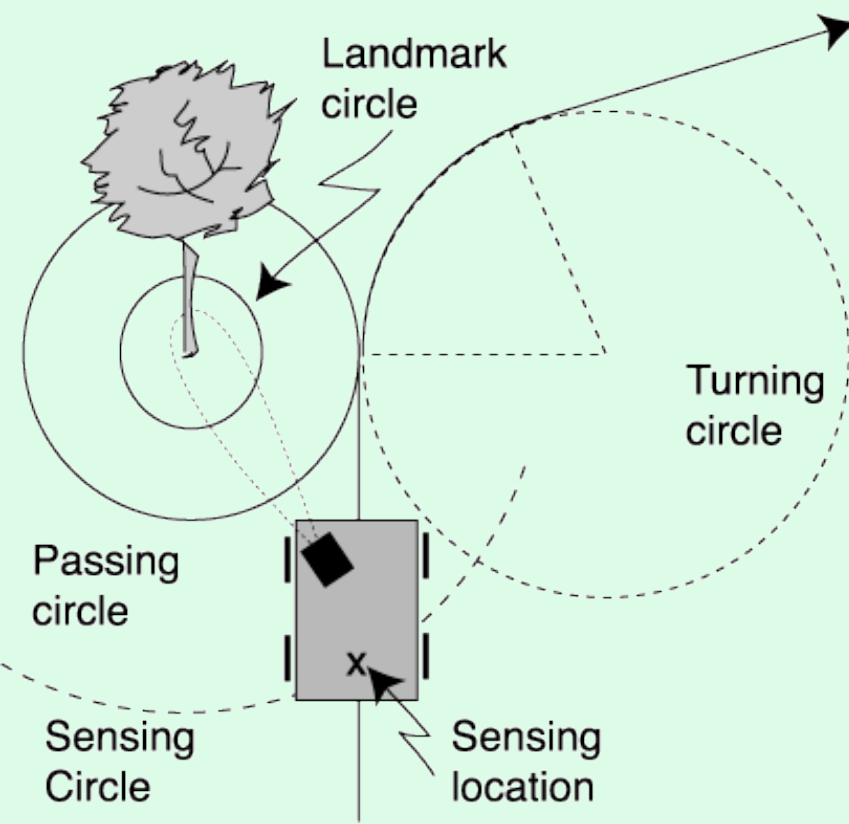
- manually drive the robot along the path
- stop at each sensing point
- calculate the distance and bearing from the previous path or landmark point
- Pan the ultrasonic sensor across the landmark and calculate a signature for use in landmark recognition

Path Planning

- Plan a navigation path with the recorded landmark points
- Determine whether to use sharp turns or curved legs

Planning a curved leg

- *Landmark circle* - model of landmark
- *Passing circle* - safe path for left turn
- *Turning circle* - path for right turn
- *Sensing point* - where the robot's path intersects the sensing circle
- *Turn radius* - specified to meet task and path constraints



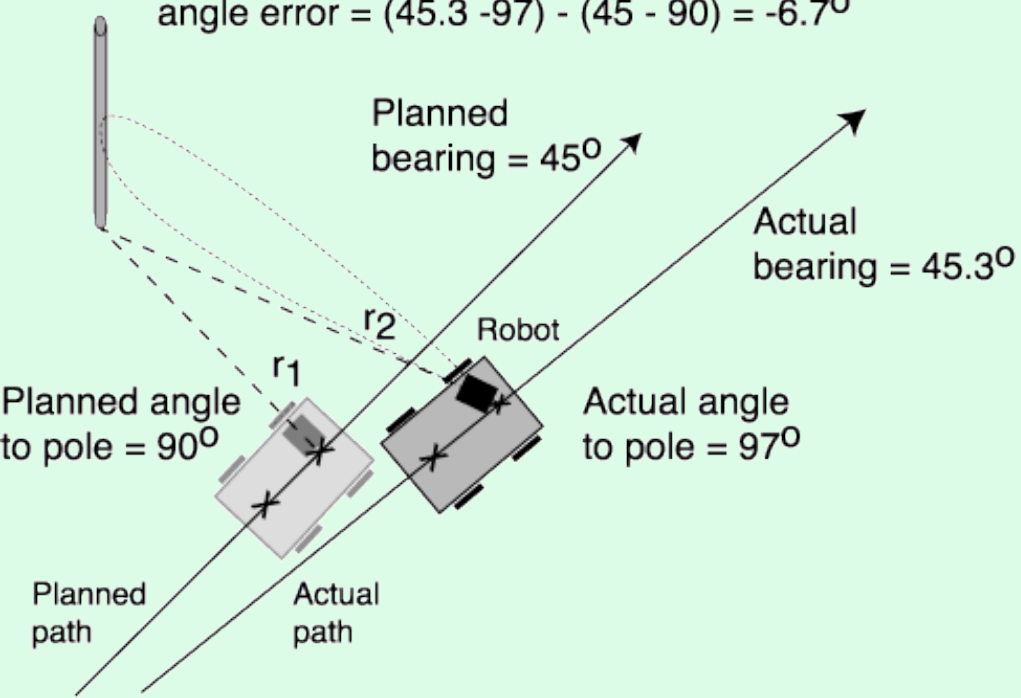
Traversing the path and localisation

Traverse each leg in the sequence.

- Stop at each landmark point and scans for the landmark.
- Locate landmark
- Calculate bearing - cross correlate scanned readings with features calculated from the recorded acoustic density profile
- Calculate the error in the robot's location relative to the planned path

Error in robot location

range error = $r_1 - r_2 = 350\text{mm}$
 angle error = $(45.3 - 97) - (45 - 90) = -6.7^\circ$

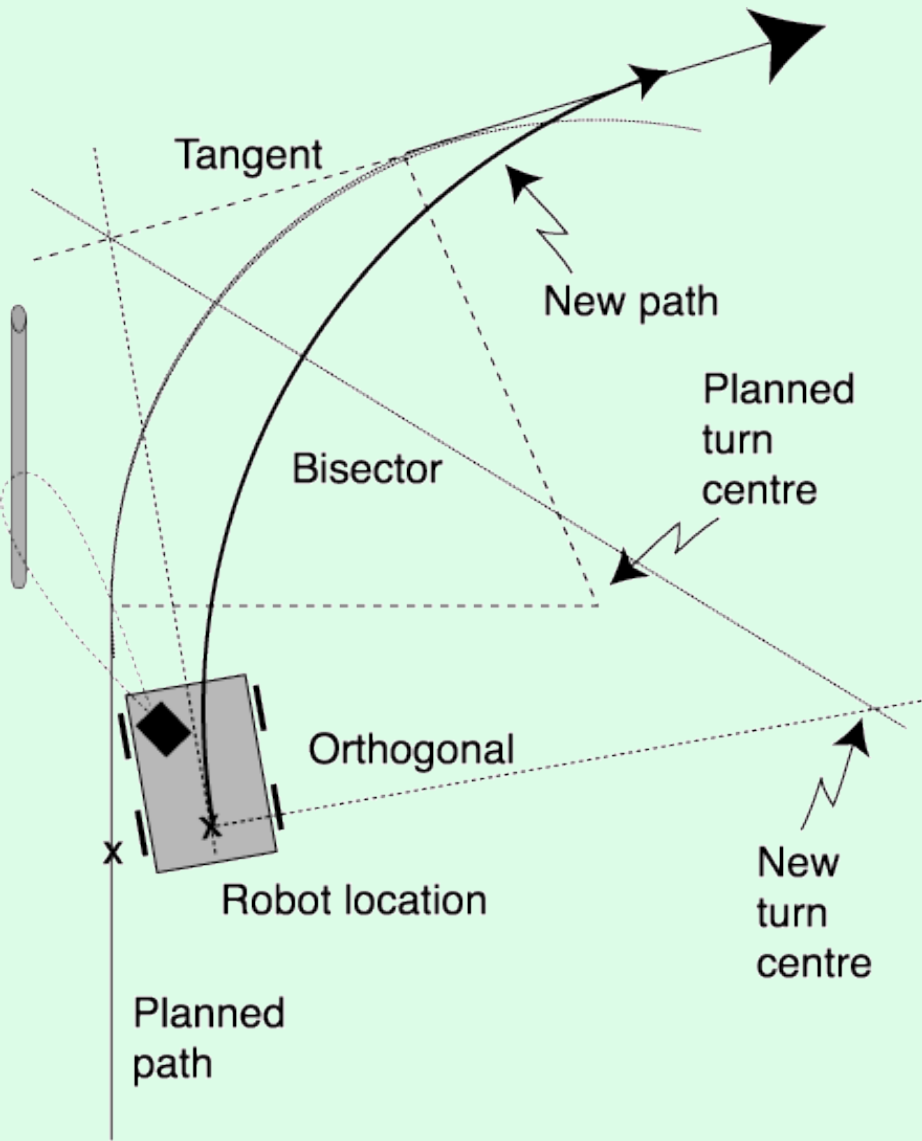


Replanning

Re-plan the subsequent leg to correct for the error

curved leg

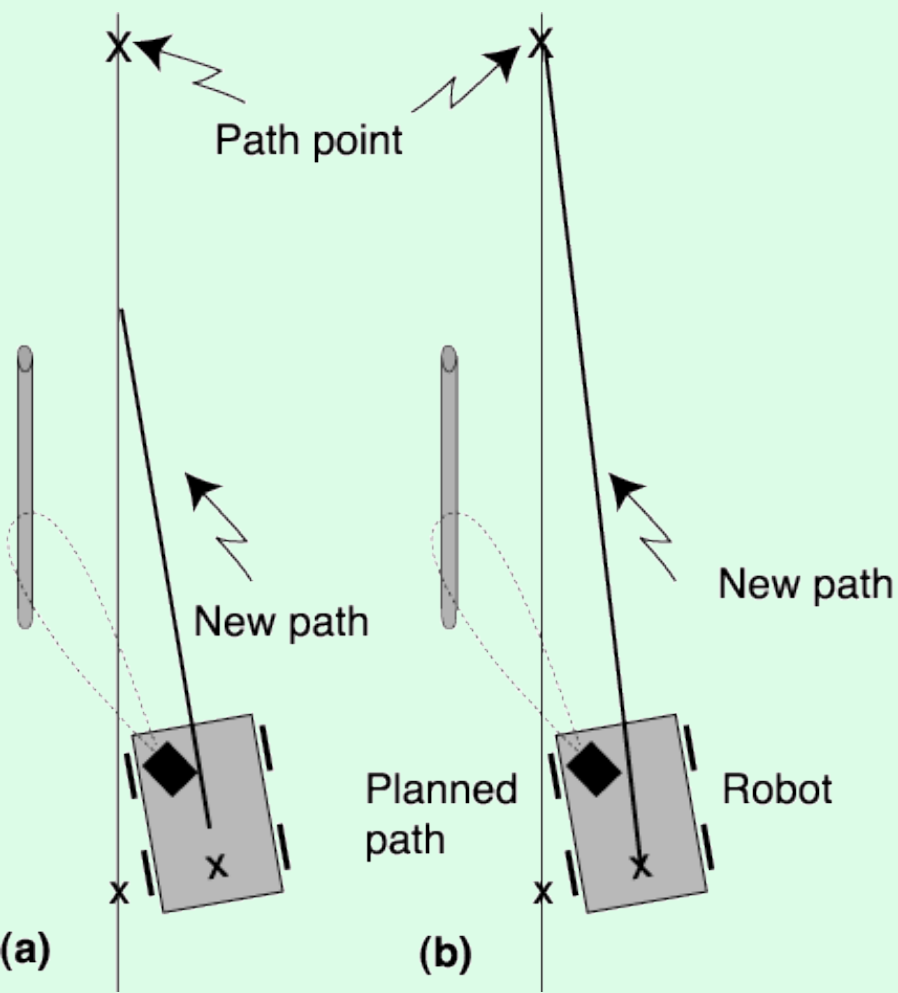
- Bisect the angle between the current vector of the robot and the desired vector of the subsequent straight leg
- Draw a line orthogonal to the current vector through the turning center of the robot
- The intersection with the bisector is the new turn center.



straight leg

two strategies for error correction

1. travel along the current vector until it intersects the path and then turn on to the planned path
2. Plan a new path from the current location to the path end point



Results

Titan [navigating](#) across sports field using poles as landmarks

82 metre path across a sports field with 4 legs

Robot experimental trajectory versus planned trajectory from DataRecorder3File25.dat

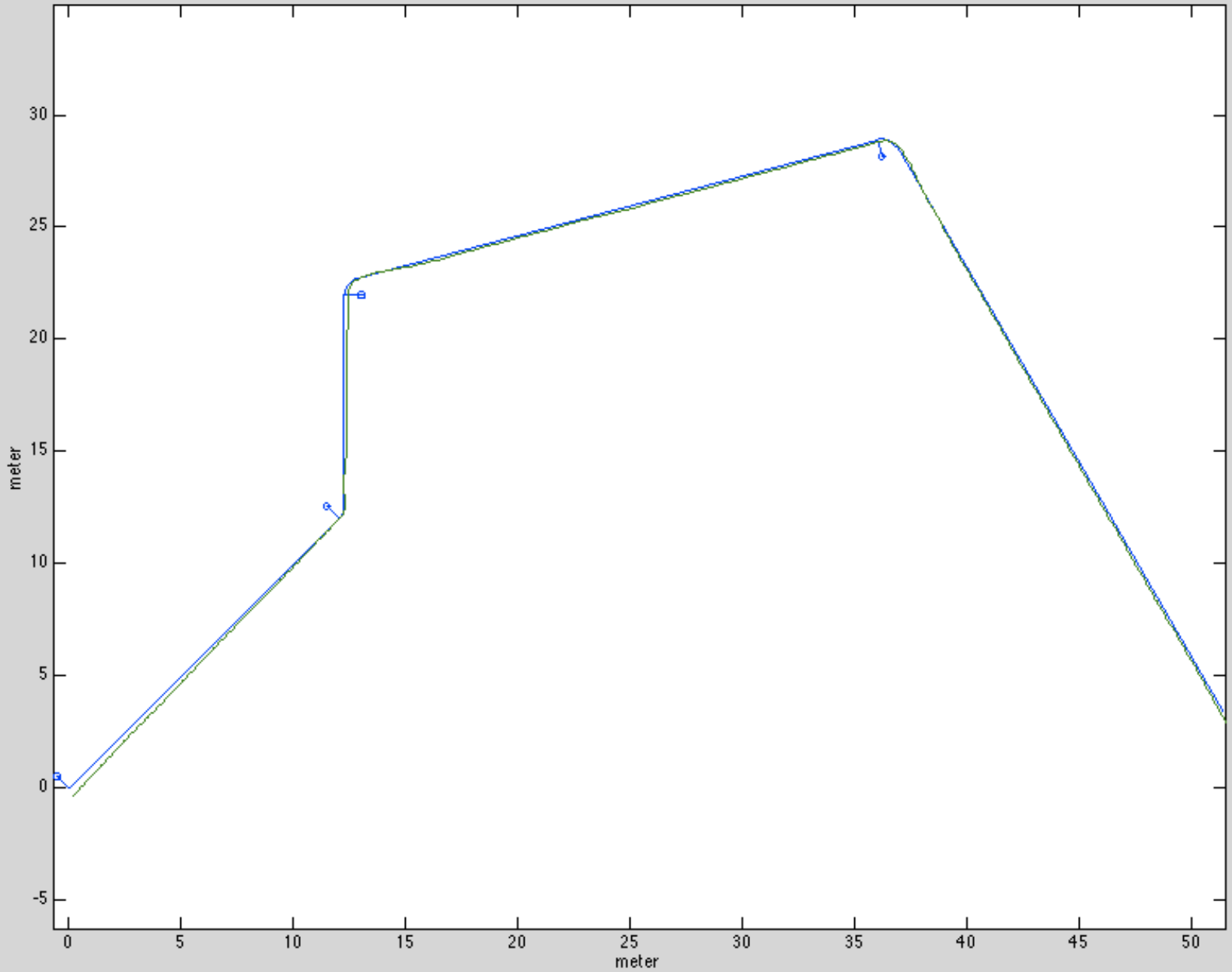


Table: Planned legs, errors and re-planned legs for above path

Leg	Leg length	Leg angle	Range error	Angle error	New length	New angle
1	17m	45o	0.35m	-6.7o	16.96	44.12
2	10m	0o	-0.06m	-6.42o	9.965	0.296
3	25m	75o	-0.04m	-6.9o	25.04	75.02
4	30m	150o	0.000	1.38o	30.0	150

Tracks on grass show the convergence of a re-planned straight leg with the planned leg



Navigation using odometry and compass [without](#) landmark sensing

A recent experiment

[Climbing](#) a ramp - autonomously

Getting the robot back [down](#) - manually

[Panic](#)

Thank you