Autonomous Vehicles

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Outline

Introduction

Unmanned Vehicles:

No driver on-board the vehicle

- Teleoperated
  - Driven by an operator viewing video feedback
  - Toy remote control car
- Autonomous
  - Driven by on-board computers using sensor feedback and automatic controls

Usage:

- Dangerous tasks
- Repetitive tasks
- Dirty tasks

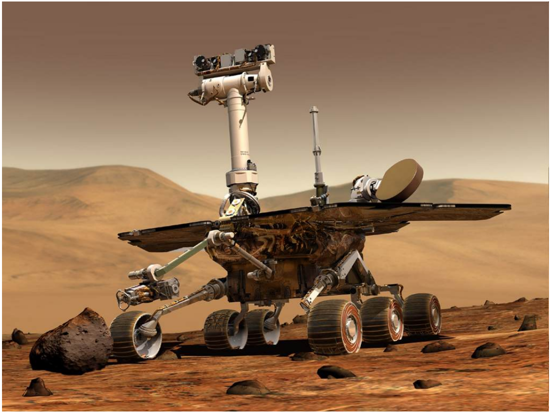
Examples

DEPTHX:
Autonomous under-water robot to explore water-filled sink holes in Mexico. The image shows a 318 meter deep sink hole.

Source: IEEE Spectrum, Sep-2007

Examples

Mars Rover by NASA



Source: http://marsrover.nasa.gov/

Examples

Stanley: The Stanford autonomous car

Source:Thrun et al. “Stanley: The robot that won the DARPA Grand Challenge”

Motivation

Source:http://www.ivtt.org/IVTT

Motivation

- Travelling by car is currently one of the most deadly forms of transportation, with over a million deaths annually worldwide
- As nearly all car crashes (particularly fatal ones) are caused by human driver error, driverless cars would effectively eliminate nearly all hazards associated with driving as well as driver fatalities and injuries

Contests and Programmes

- EUREKA Prometheus Project (1987-1995)
- ARGO Project, Italy (2001)
- DARPA Grand Challenge (2004-2007)
- European Land-Robot Trial (2006-2008)

EUREKA Prometheus Project

VaMP and VITA-2 vehicles (1994)

- 1000 km on a Paris multi-lane highway in heavy traffic at up to 130 km/h
- Autonomous convoy driving, vehicle tracking, lane changes, passing of other cars

Autonomous Mercedes S-Class in 1995

- 1000 km on the German Autobahn at 175 km/h
- Not 100% autonomous. A human safety pilot was present
- Car drove upto 158 km without intervention

DARPA Grand Challenge

- US Department of Defense conducts the autonomous vehicle challenge
- 2004: Mojave Desert, United States, along a 150-mile track
- 2005: 132 mile off-road course in Nevada
- 2007: 'Urban Challenge' at George Air Force Base

Typical Challenges to meet

- Navigate desert, flat and mountainous terrain
- Handle obstacles like bridges, underpasses, debris, potholes and other vehicles

- Obey traffic laws
- Safe entry into traffic flow and passage through busy intersections
- Following and overtaking of moving vehicles
- Drive an alternate route when the primary route is blocked
- Correct parking lot behaviour
- Most important rule: No Collisions

DARPA 2005 Track

Source:Google Videos: The Car That Won The DARPA Grand Challenge: 2006"

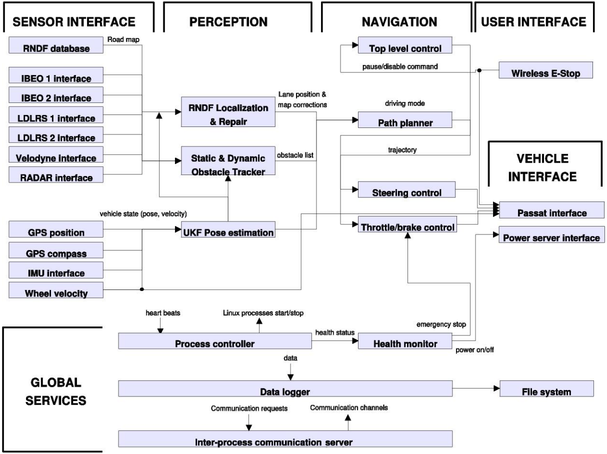
DARPA 2007 Track

Source:DARPA Urban Challenge Participants Conference Presentation

What should an autonomous vehicle do?

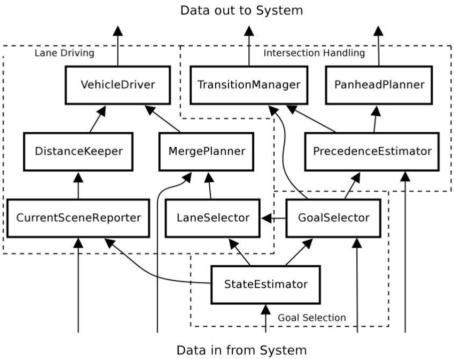
- Understand its immediate environment (Perception)
- Find its way around obstacles and in traffic (Motion planning)
- Know where it is and where it wants to go (Navigation)
- Take decisions based on current situation (Behaviour)

Architecture: Junior (Stanford)



Source:Thrun et al. “Junior: The Stanford Entry in the Urban Challenge”

Architecture: Boss (CMU)

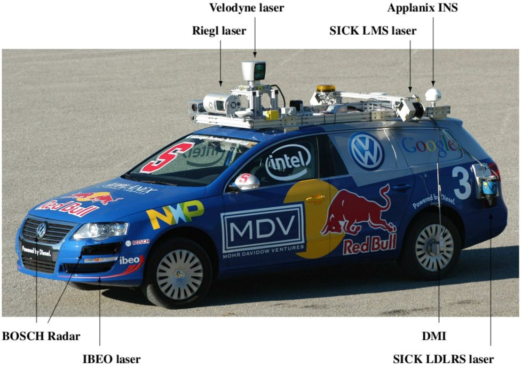


Source: Urmson et al. "Autonomous Driving in Urban Environments: Boss and the Urban Challenge"

Perception

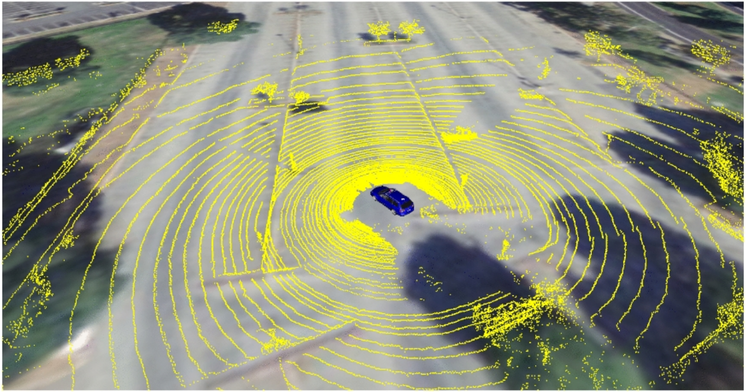
- LIDAR (Light Detection and Ranging)
- RADAR
- Vision
- GPS
- Inertial navigation system

Sensors on Stanley, The Stanford Car



Source:Thrun et al. "Stanley: The robot that won the DARPA Grand Challenge"

LIDAR



Source:Thrun et al. “Junior: The Stanford Entry in the Urban Challenge”

LIDAR for Obstacle Detection

- Long range scanner has several lasers, each with a scanning ring
- Compare radius of adjacent rings to identify height of objects
- Use multiple short range LIDARs to cover blind spots
- Generate a point cloud based on LIDAR data
- Apply thresholds to this data to eliminate overhanging and low objects

Handling Occlusion

- Objects may not be always visible
- Integrate range data over time, to keep track of objects that may be temporarily occluded

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What about Moving objects?

Handling Occlusion

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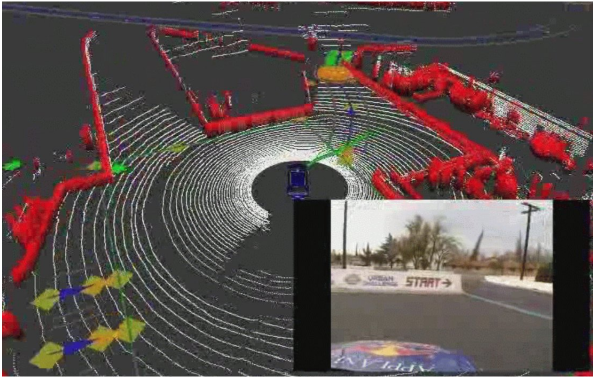
What about Moving objects?
Integrate data only in those regions that are currently occluded

Obstacle Detection in action

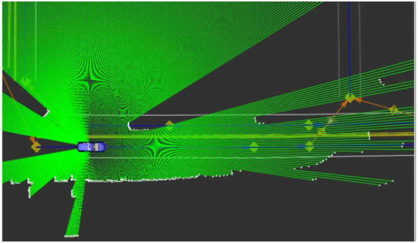


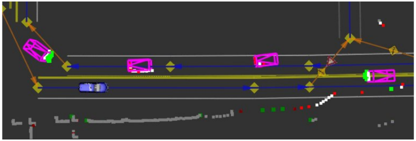
Source:Thrun et al. "Junior: The Stanford Entry in the Urban Challenge"

Object Tracking

- Identify and label distinct moving objects
- Obtain information about these objects, such as size, heading and velocity
- Continue to track these objects (even when they are occluded)

Object Tracking





Source:Thrun et al. "Junior: The Stanford Entry in the Urban Challenge"

Object Tracking: Details

- Identify areas of change
- Initializes a set of particles as possible object hypotheses
- These particles implement rectangular objects of different dimensions, and at slightly different velocities and locations
- A particle filter algorithm is then used to track such moving objects over time

Further Challenges in Perception

- What is a road?
- Self Localization
- Bad/Noisy data
- Sensor failure (ex: GPS outage)
- Setting 'good' thresholds

Motion Planning

Motion planning involves performing low level operations towards achieveing some high level goal

Path Variables:

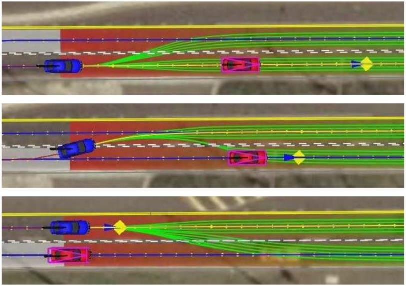
- Steering (direction)
- Speed

Planning:

- Vary these parameters and generate multiple local paths that can be followed
- Assign costs to paths based on time taken, distance from obstacles, and other constraints
- Choose the best path from the various possible paths

Varying direction

Direction is varied by tracing possible paths from current position to a set of (temporary) local goals. These goals are slightly spread out so as to be able to navigate around obstacles. Paths of greater length, paths that are near obstacles incur higher cost.

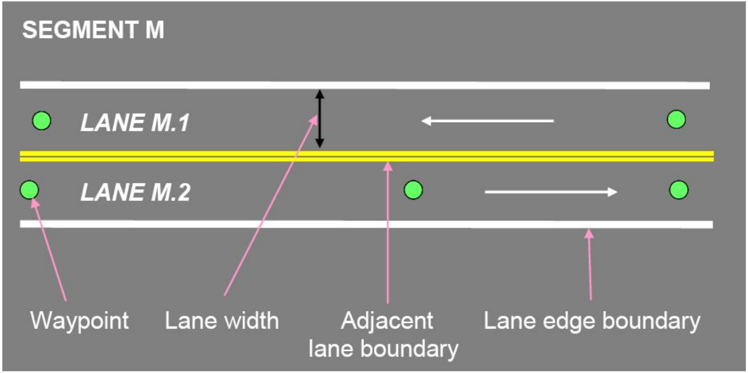


Source:Thrun et al. “Junior: The Stanford Entry in the Urban Challenge”

Mission Planning

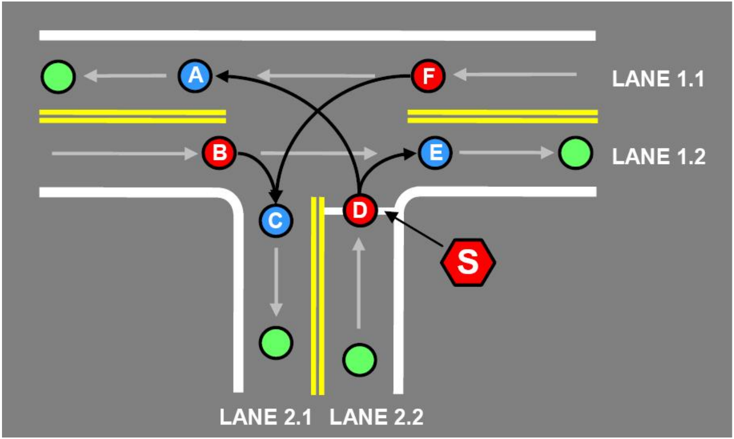
- Global Path Planning
- DARPA Urban Challenge: input files
  - Route Network Definition File (RNDF)
  - Mission Data File (MDF)

Road Segment



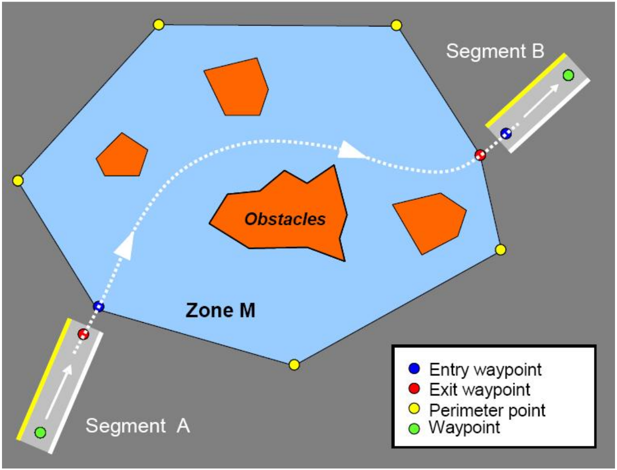
Source:DARPA Urban Challenge Participants Conference Presentation

Stop Lines



Source:DARPA Urban Challenge Participants Conference Presentation

Zones



Source:DARPA Urban Challenge Participants Conference Presentation

Connectivity Graph

- Connectivity Graph
- Edges are assigned costs based on
  - Expected time to traverse the edge
  - Distance of the edge
  - Complexity of the corresponding area of the environment
- Value function
  - Path from each way point to the current goal
  - Incorporating newly observed information

Blockage Detection

- Static obstacle map
- Spurious Blockages
- Efficient, optimistic algorithm: Some blockages are not detected
- Virtual Blockage
- Extent of the blockage along affected lanes

Revisiting Blockages

Revisiting of previously detected blockages

- The cost c increment added by a blockage is decayed exponentiallys
- $c = p2^{-a/h}$ where
  a is the time since the blockage was last observed,
  h is a half-life parameter,
  p is the starting cost penalty increment for blockages
- Cost Threshold

Avoiding too frequent visits to a blockage:

- Increment h for the blockage after each new visit would make the traversal costs decay more slowly each time the obstacle is observed

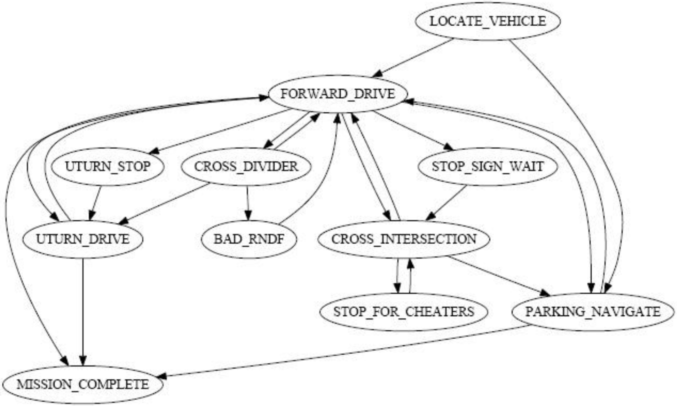
Blockage Handling: Challenges

- Blockages on one-way roads
- No legal U-turn locations
- The zone navigation planner is invoked as an error recovery mode

Behavioural Reasoning

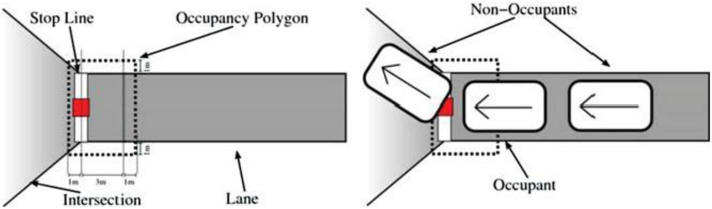
- Executing policy generated by the mission planner
- Lane changes, precedence, safety decisions
- Error recovery

Behavioural Reasoning: Finite State Machine



Source: Thrun et al. "Junior: The Stanford Entry in the Urban Challenge"

Intersection and Yielding



Source: Urmson et al. "Autonomous Driving in Urban Environments: Boss and the Urban Challenge"

Precedence estimation

- Obeying precedence
- Not entering an intersection when another vehicle is in it
- Road model
- The moving obstacle set

Road model

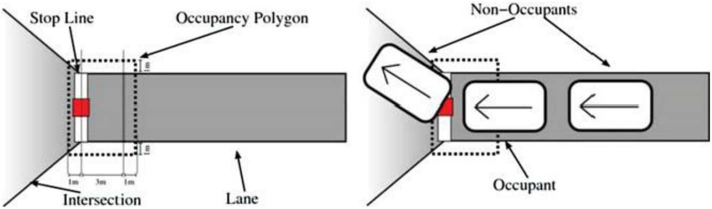
The road model provides important data, including the following:

- The current intersection of interest, which is maintained in the world model as a group of exit way points, some subset of which will also be stop lines
- A virtual lane representing the action the system will take at that intersection
- A set of yield lanes for that virtual lane
- Geometry and speed limits for those lanes and any necessary predecessor lanes

Moving Obstacle Set

- Received periodically
- Represents the location, size, and speed of all detected vehicles around the robot
- Highly dynamic Data
- Tracked vehicles can flicker in and out of existence for short durations of time
- Sensing and modeling uncertainties can affect the estimated shape, position, and velocity of a vehicle
- The process of determining moving obstacles from sensor data may represent a vehicle as a small collection of moving obstacles
- Intersection centric vs. vehicle-centric precedence estimation algorithm

Precedence Estimation Algorithm

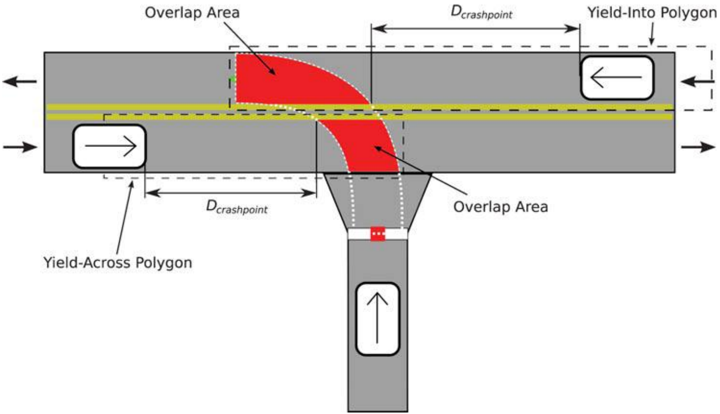


Source: Urmson et al. “Autonomous Driving in Urban Environments: Boss and the Urban Challenge”

Merging

- Merging into or across moving traffic from a stop
- Next intersection goal: Virtual Lane
- Yield Lanes

Yielding



Source: Urmson et al. "Autonomous Driving in Urban Environments: Boss and the Urban Challenge"

Yielding

- Temporal Window
- $T_{required} = T_{action} + T_{delay} + T_{spacing}$
- where
  - $T_{required}$: time to traverse the intersection and get into the target lane
  - T_{delay} : maximum system delay
  - $T_{spacing}$: minimum required temporal spacing between vehicle

Applications

- Military uses:
  - Surveillance and Reconnaissance
  - Clearing Mines
  - Transporting Supplies/troops
- Civilian uses:
  - Robots dont drink/sleep/use cellphones...
  - Help incapacitated people to drive
  - Increase productivity
  - Increase road throughput

Conclusion

- Autonomous vehicles have come a long way since 2004
- Effective navigation even in bad weather
- Networks of autonomous vehicles could allow interaction and prevent collisions, traffic jams etc

Unsolved Problems

- Traffic Signals
- Pedestrians
- Live Traffic Jams
- Computational Power
- Non-standard environments
- Interaction with Humans

References

1 Sebastian Thrun et al. "Stanley: The robot that won the DARPA Grand Challenge", Journal of Robotic Systems, vol. 23, no. 9, 2006.

2 Chris Urmson et al. "Autonomous Driving in Urban Environments: Boss and the Urban Challenge", Journal of Field Robotics 25(8), 425-466 (2008)

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6 Gustafsson et al. "Particle filters for positioning, navigation, and tracking", IEEE Transactions on Signal Processing, 2002