

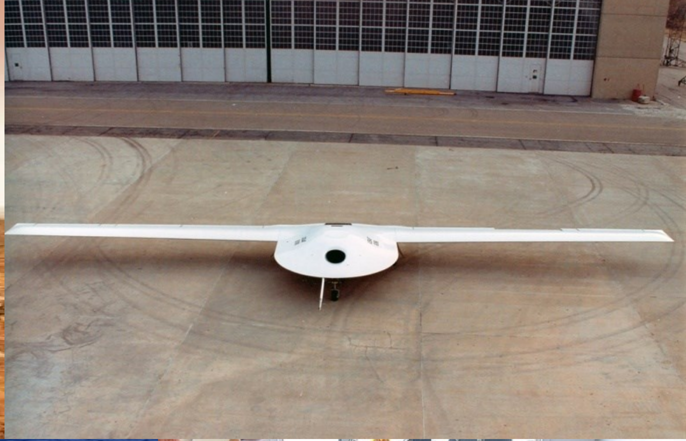


ME 597/780 Autonomous Mobile Robotics
Section 1: Introduction

Prof. Steven Waslander

Syllabus

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SYLLABUS

- Lectures:
  - Tuesday 12:30 – 2:00pm, RCH 112
  - Wednesday 4:00pm – 5:30pm, RCH 110
  - Next week Tues/Wed cancelled due to travel
  - Make up lecture time – Friday morning 9:30-11?

- Communication:
  - Emails through UW-Learn class list
  - Slides, code, homework posted to UW-Learn now
    - All corrections noted with revision number
  - Labs posted before start of lab sessions
    - Turtlebots in second year, should run smoothly

Syllabus

- Resources
  - Course Notes
    - Updated versions posted after lectures on UW-Learn
    - Notes include all Powerpoint slides + all Matlab code used to generate examples. You must regenerate movies on your own by running the Matlab scripts (currently 5 GB of videos in my lectures folder).
  - Recommended Texts (none required)
    - Autonomous Mobile Robots, 2nd Ed., Siegwart, Nourbakhsh, Scaramuzza
    - Probabilistic Robotics, 3rd Ed., Thrun, Burgard & Fox
    - Principles of Motion Planning, Choset et al.

Syllabus – ME 597 Labs

- Three labs this year
  - Simulation first, then a day with a Turtlebot
  - Make it do something autonomously in every lab

- Lab #1 – Full Autonomous Navigation using existing ROS packages.
- Lab #2 – SLAM: Build a map of the environment while traveling through it, without global position information.
- Lab #3 – Planning: Using Indoor Positioning and a known map, plan a route from one point to another.

Syllabus – ME 597 Labs

- Labs:
  - **Please form teams of 3-4 people and sign up for a group on Learn corresponding to a particular week day by Friday, Sept 12**.
    - Groups 1-6 – Monday, 7-12 – Tuesday, 13-18 – Thursday, 19-24 - Friday
    - 4 days * 6 robots * 3-4 p/group = 72-96 people in class
    - Lab 1 starts Monday, Sept 22 – very soon
      - Must have Linux laptop, ROS installed and try out Turtlebot demos in simulation ahead of time
    - Don't waste TA's time, come prepared for the lab

  - Lab reports are due as a single pdf on Learn on the Friday one week after all the labs are completed. Late labs will have 25% of the lab mark deducted for each day or part of a day that the lab is late.

Syllabus – ME 597 Labs

Lab #1	**Week 1: Sept 22-26** **Week 2: Sept 29-Oct 3** **Due: Oct 10, 5 PM, dropbox submission of pdf.**
Lab #2	**Week 1: Oct 20-Oct 24** **Week 2: Oct 27-Oct 31** **Due: Nov 7, 5 PM, dropbox submission of pdf.**
Lab #3	**Week 1: Nov 17-21** **Week 2: Nov 24-28** **Due: Due Dec 12, 5PM, dropbox submission of pdf.**

Syllabus

- Assignments
  - Matlab simulation exercises similar to exam questions.
  - Write up or type up solution neatly, more instruction to follow as part of assignment handout.
  - Groups of up to two students to submit solution, can collaborate with others, but one write up per group.

Assignment #1	**Assigned: Oct 1st** **Due: Oct 24th, Dropbox submission of pdf.**
Assignment #2	**Assigned: Nov 5th** **Due: Dec 4th, Dropbox submission of pdf.**

Syllabus

- Tutorials
  - Lab related, explanation of hardware, software, ROS
    - Week of Sept 15th, regular class time.
    - Tuesday, Sept 16th, Last name A-M
    - Wednesday, Sept 17th, Last name N-Z
    - Location TBD, will post on Learn.
  - Matlab tutorial, related to assignments, final
    - Week of Oct 6th
    - Evening, 6-8, 7-9?

Syllabus– ME 780 Projects

- Topic of your choosing
- Involve implementation in simulation or on real hardware wherever possible
- Only limited hardware available
  - Lab robots when not in use,
  - Some other platforms in my/other labs (talk to me)
- Groups of up to three students

Syllabus – ME 780 Projects

- **Project proposal due on Friday, September 26th, Dropbox submission by 5PM (10%).**
- Mid-project Updates due Friday, November 7th, Dropbox submission by 5PM (10%).
- Presentation of results in the week of December 1st, whole class invited (30%).
- Final report due on Friday, December 12th, in two column IEEE conference paper format not to exceed 6 pages (50%).

Syllabus – ME780 Projects

- Project Proposal
  - Outline problem, applications
  - Solution method
  - Goals for semester
  - Relationship to course
  - Hardware/software used
    - Status of hardware
- Will get feedback on proposals, update, presentation and in meetings.
- Meetings as needed, but try to book at least one.
  - Email to book all meetings.

Syllabus

- Final Exam
  - Exam date to be selected by class
  - Exam posted to UW-Learn, return solutions in 24 hours in Dropbox.
  - Although you have 24 hours to complete it, the exam should take 10-16 hours of work.
  - Should only need course notes, Matlab, paper.
  - Questions will closely follow Matlab code examples provided with lecture notes.
  - **No talking to anyone about any aspect of the exam for the entire exam period! This is crucial, there is no grey area. Do not cheat.**

Syllabus

- Additional Problems

  - There are currently two problem sets, reflecting final type questions.

  - Each section of the course also has challenge problems associated with it, which are excellent tests of you understanding of the material, and often become final questions.

  - No solutions exist for the challenge problems, but I will happily discuss any of your solutions with you.

Syllabus

- Prerequisites
  - Linear Algebra
  - Probability Theory
  - State Space Modeling
  - Matlab

- Useful skills
  - Linux, C++, make, ROS etc.
  - Control theory
  - Estimation theory
  - Optimization theory

Syllabus

- ME 597 Grading:
  - 30% Labs
  - 20% Assignments
  - 50% Final Exam

- ME 780 Grading:
  - 20% Labs
  - 15% Assignments
  - 30% Project
  - 35% Final Exam

- Sitting in on lectures
  - More than welcome
  - No requirements, enjoy, ask questions!

Syllabus

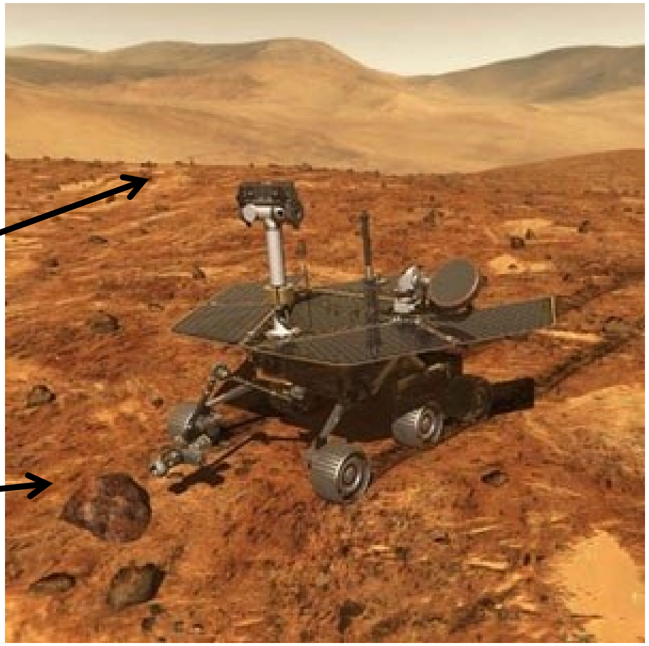
- Questions?

Course Overview

- Define Autonomous Vehicle:

A mobile platform capable of safely operating to achieve a predefined goal in the face of unpredictable events.

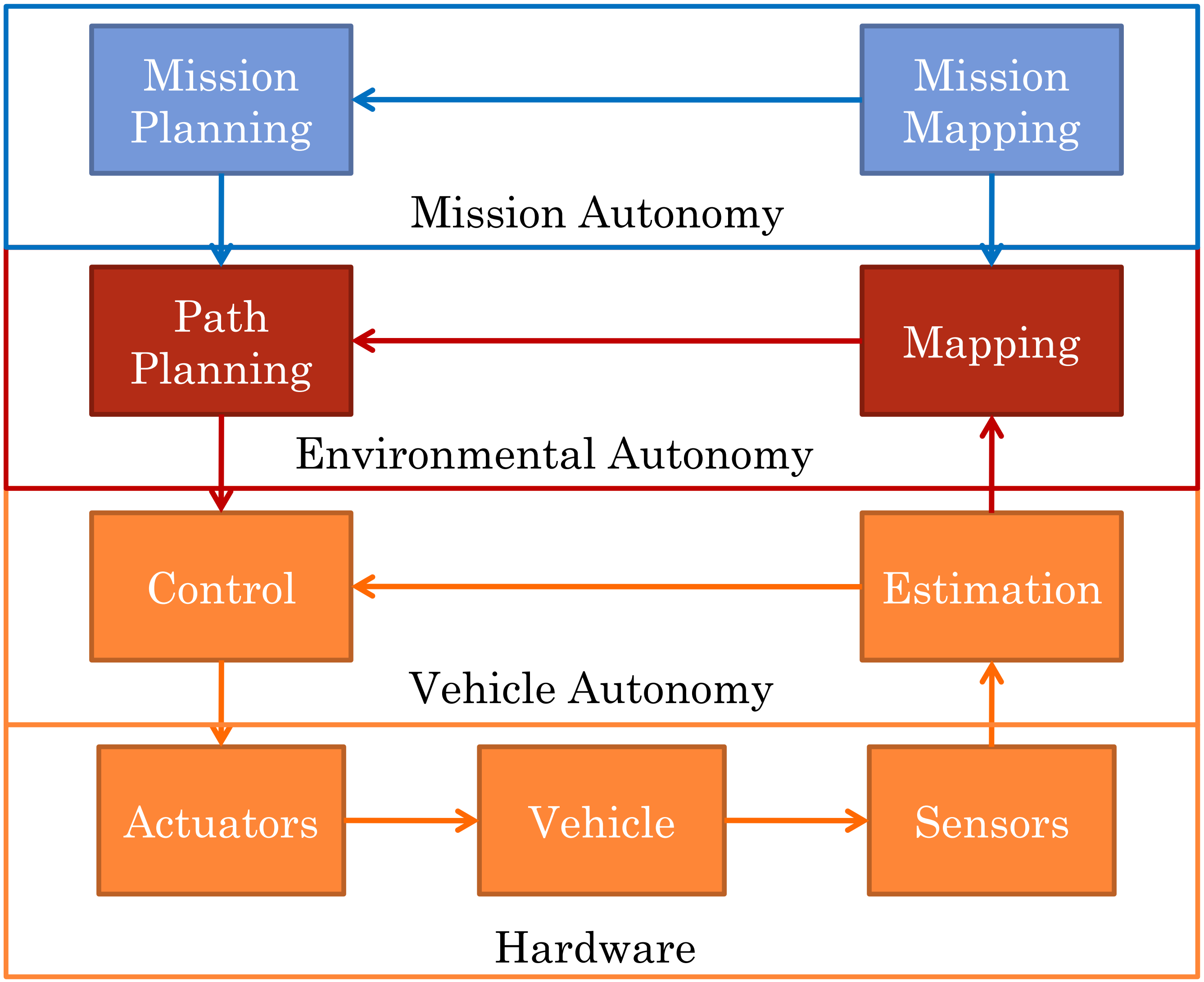
- Very flexible definition
    - Could be referring to PID control: goal = zero error, unpredictable events = sensor/actuator noise
    - Or Mars exploration



Go here, we'll check back in 40 minutes

Watch out for this, though!

Course Components



Course Content

- 1 – Introduction
- 2 – Review of Linear Algebra, State Space Modeling, Probability
- 3 – Coordinate Transforms & Motion Modeling
- 4 – Sensors & Measurement Modeling
- 5 – Estimation: Bayes, Kalman, EKF, Particle
- 6 – Mapping: Localization, Mapping, SLAM
- 7 – Control: Linear, Nonlinear
- 8 – Planning: Local, Graph-based, Probabilistic, Optimal
- 9 – Quadrotor Research, Review

Class Survey

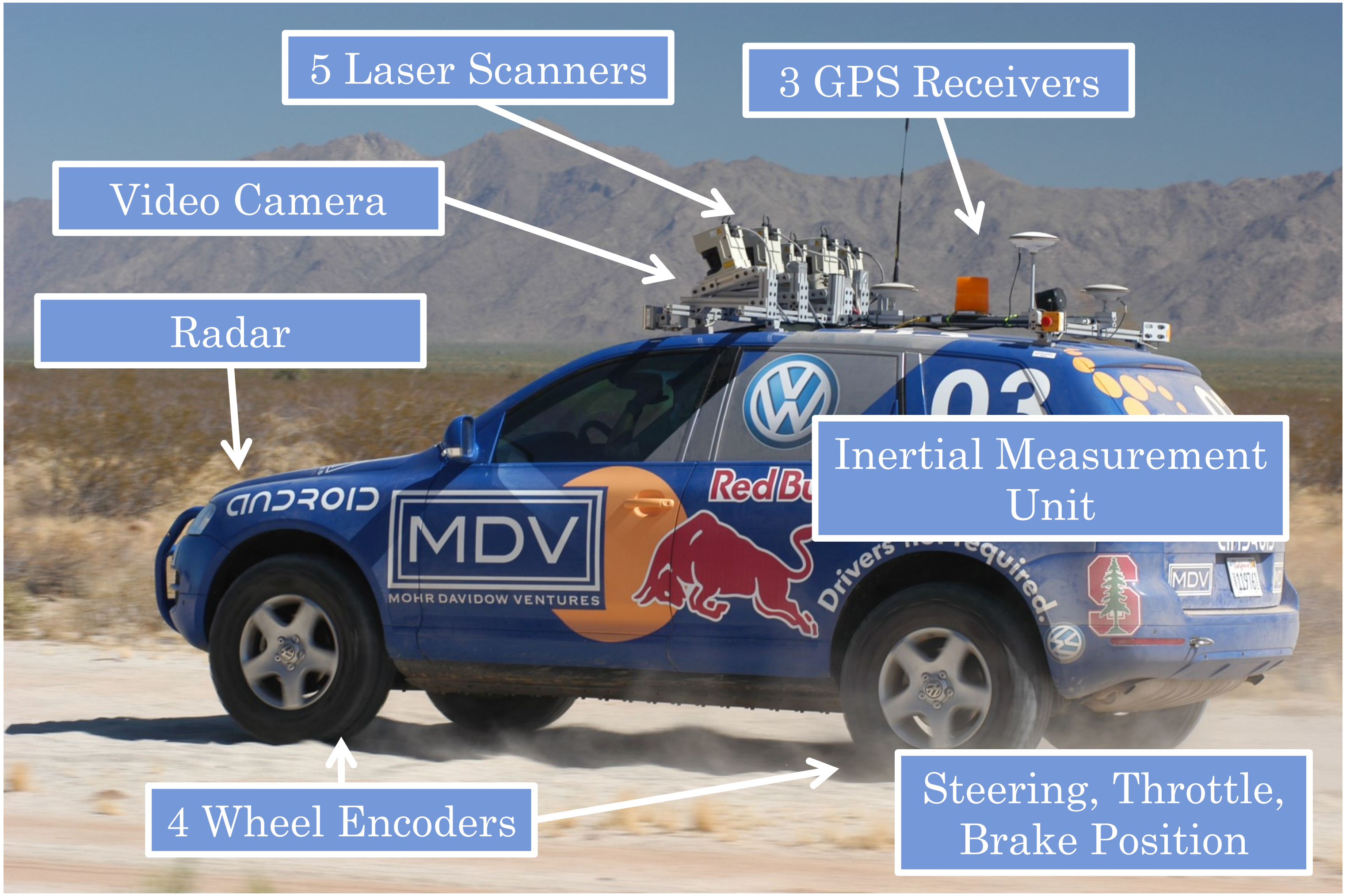
- How many of you have…
  - Used Matlab?
  - Coded in C/C++/Java?
  - Used ROS?
  - Worked with GPS, vision, lasers, SODAR?
  - Built their own robot?
  - Studied probability theory?
  - Know the difference between local and global maxima?
  - Seen Linear Programming, Nonlinear Programming?
  - Seen Kalman Filters, EKFs, UKFs, Particle Filters?
  - Implemented a SLAM algorithm?
  - Seen the Iterated Closest Point algorithm?
  - Found the shortest path on a graph?
  - Seen the Wavefront algorithm, Probabilistic Roadmaps, Rapidly-expanding Random Trees?

The Google Car Lineage

- The evolution of autonomous driving

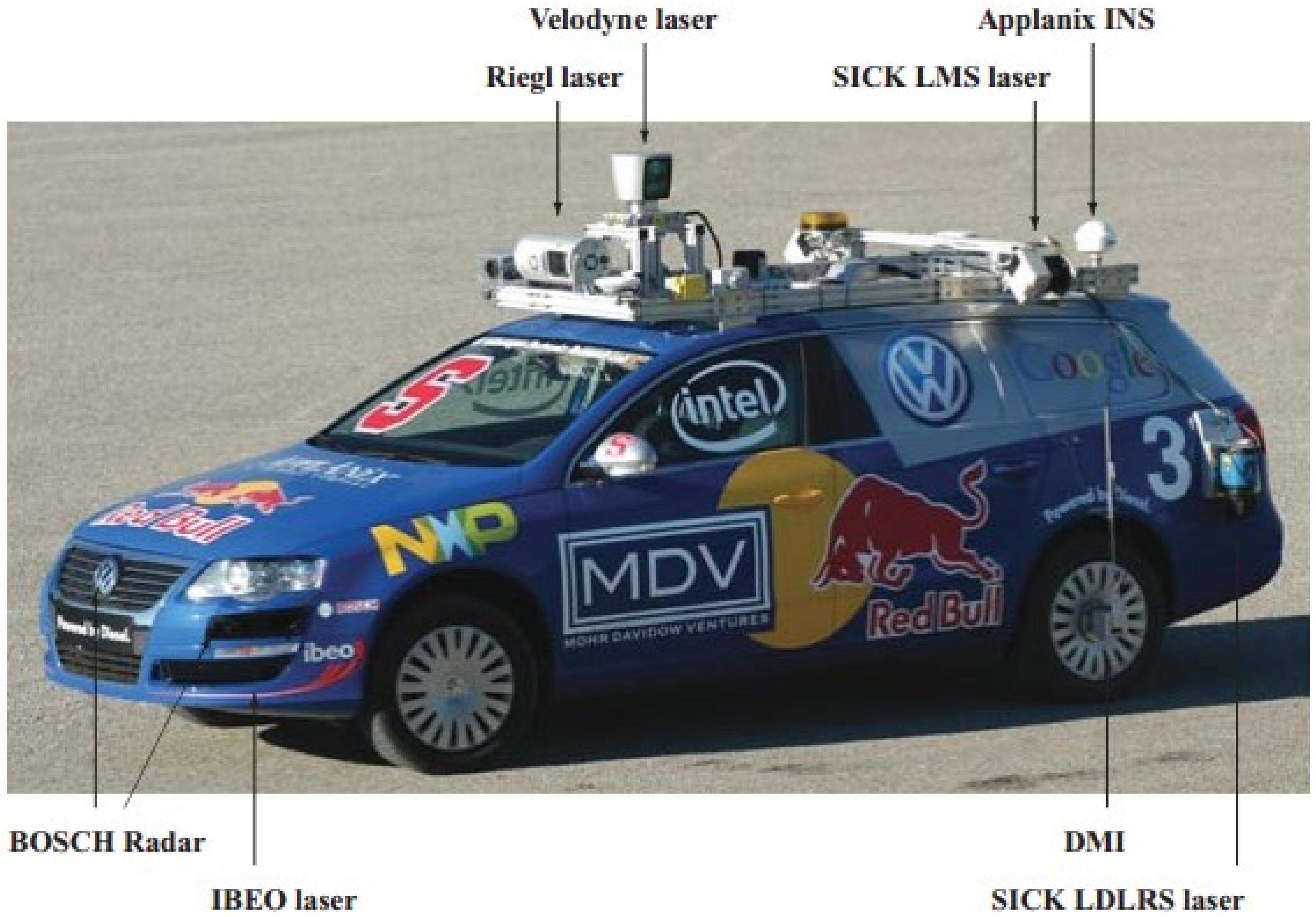
Sensors

- Stanley



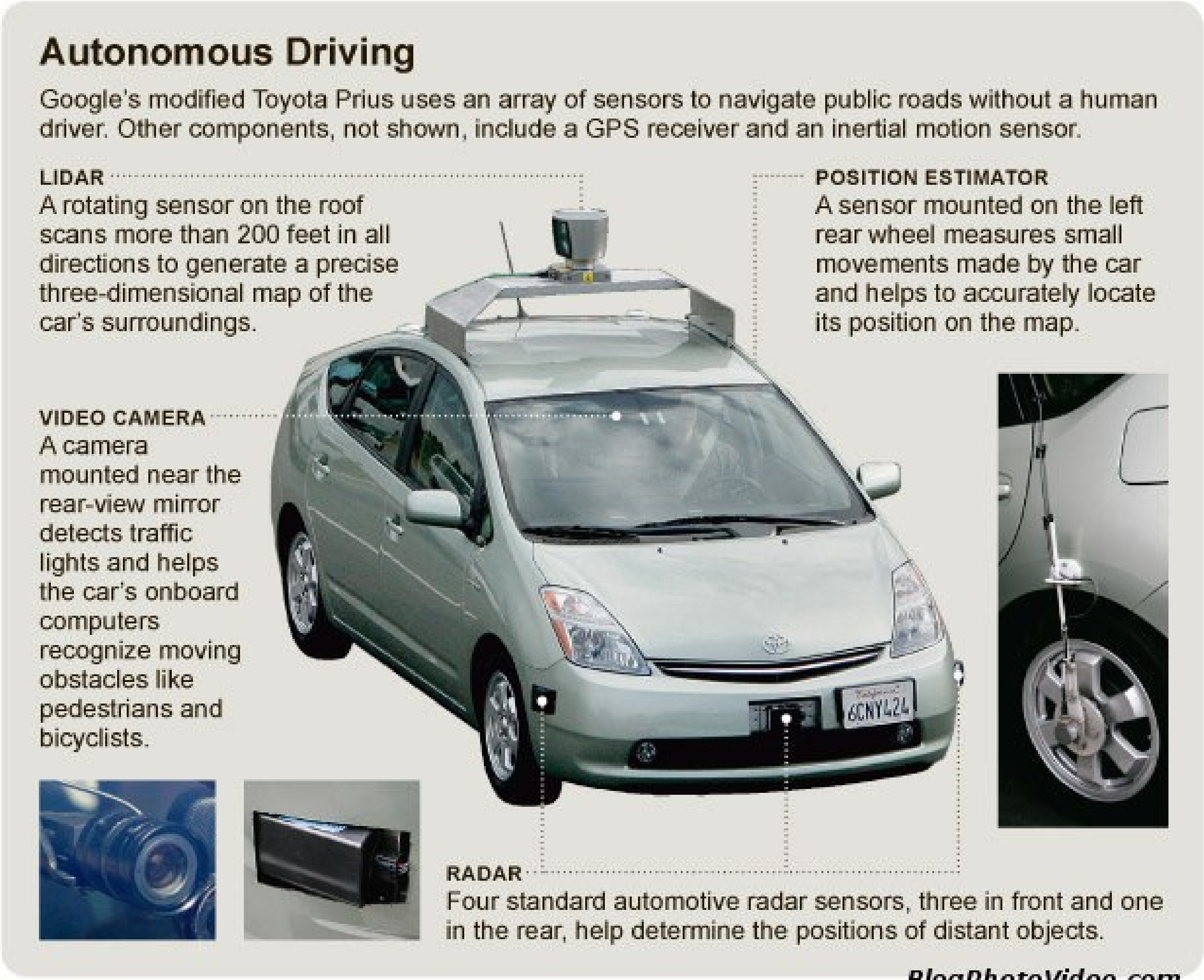
Sensors

- Junior



Sensors

- Google Car

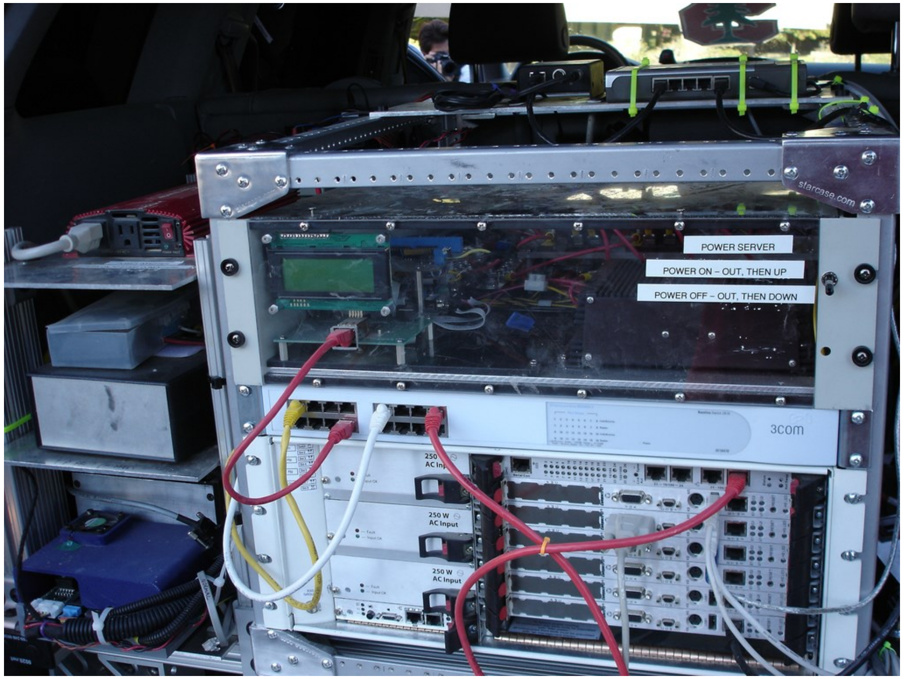


Source: Google

BlogPhotoVideo.com

Computation

- Stanley
  - 6 Pentium-Ms in rugged rack mount
  - Networked interfaces for independent computations
  - Battery backup



- Communication
  - RF E-stop
  - Nothing else!

Computation

- Junior
  - Two Intel quad core servers running Linux
  - Communication over a gigabit Ethernet link
  - Custom drive-by-wire interface developed by Volkswagen

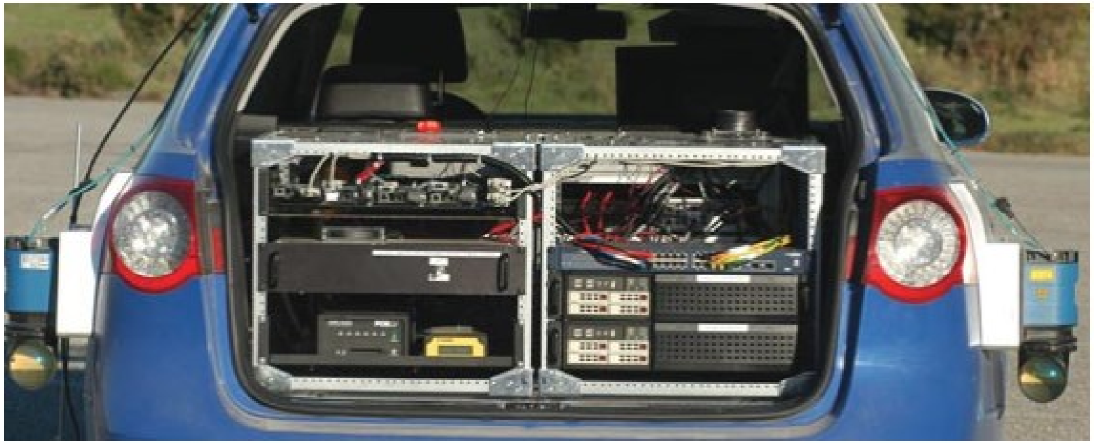
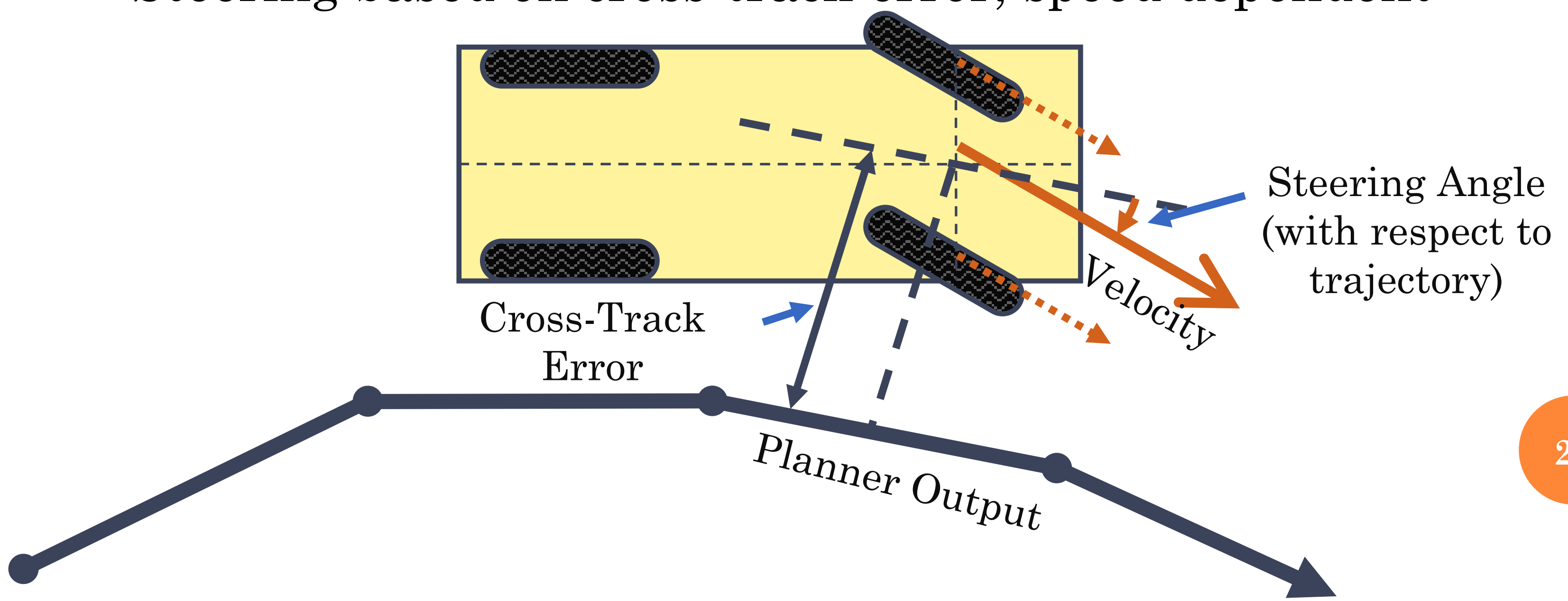


Figure 2. All computing and power equipment is placed in the trunk of the vehicle. Two Intel quad core computers (bottom right) run the bulk of all vehicle software. Other modules in the trunk rack include a power server for selectively powering individual vehicle components and various modules concerned with drive-by-wire and GPS navigation. A six-degree-of-freedom inertial measurement unit is also mounted in the trunk of the vehicle, near the rear axle.

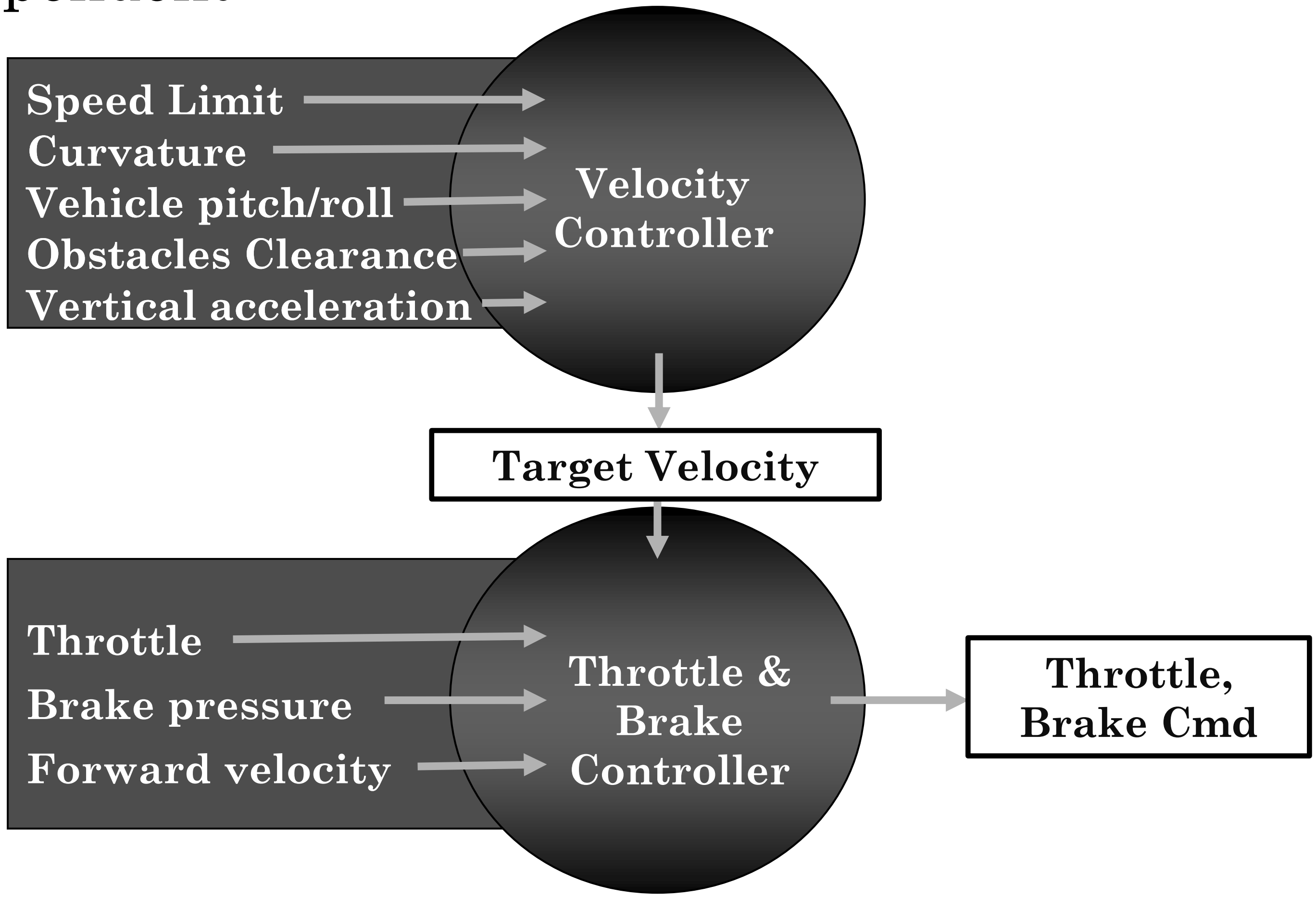
Vehicle Control

- State Estimation
  - Stanley - Combining GPS, IMU, Wheel Odometry using Extended Kalman Filtering
  - Google Car – LIDAR and IMU mostly, GPS for map reference only
- Steering Control
  - Steering based on cross-track error, speed dependent



Speed Control

- Complex reference speed calculation
- Nonlinear throttle/brake actuation, speed dependent



Stanley

- Human vs Robot Driver

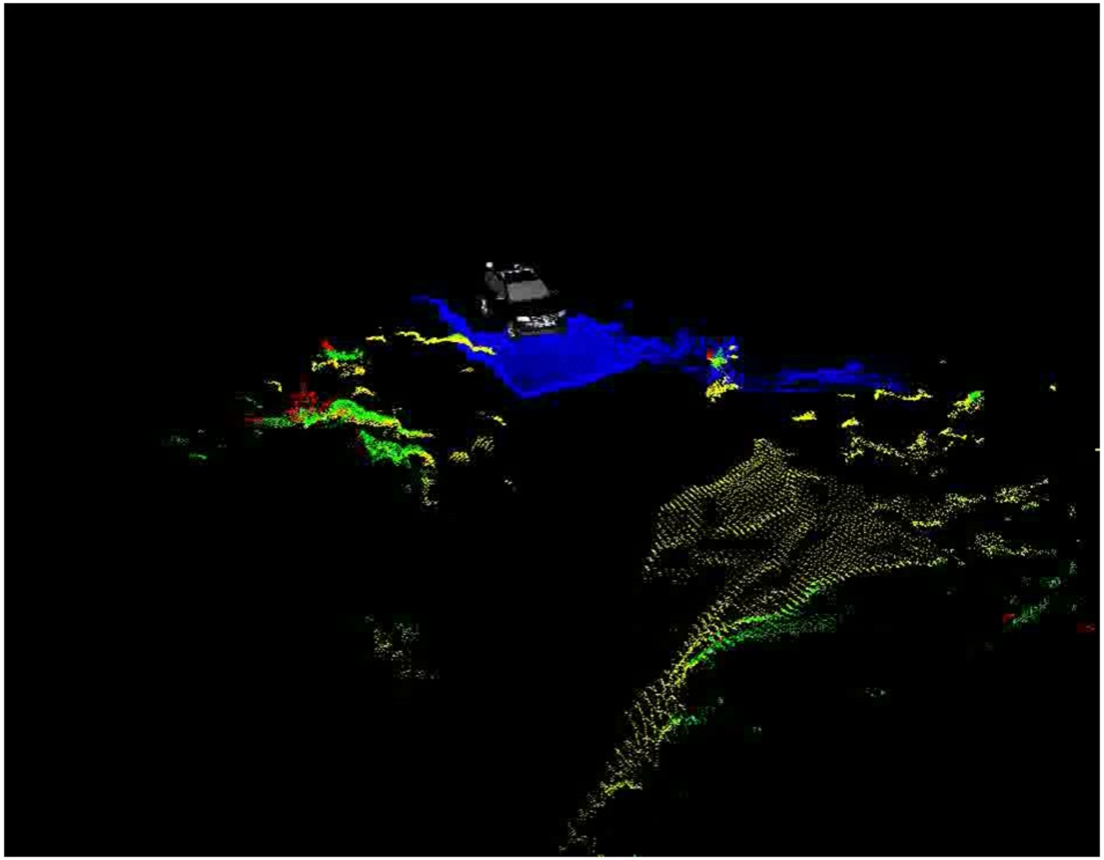
MAPPING

- Stanley
  - Key Mapping Need: Drivable vs Undrivable

1. Use lasers to create accurate short lookahead terrain map (3 separate angles)
2. Use vision to identify road direction in the distance
3. Use radar to detect obstacles up to 200m ahead

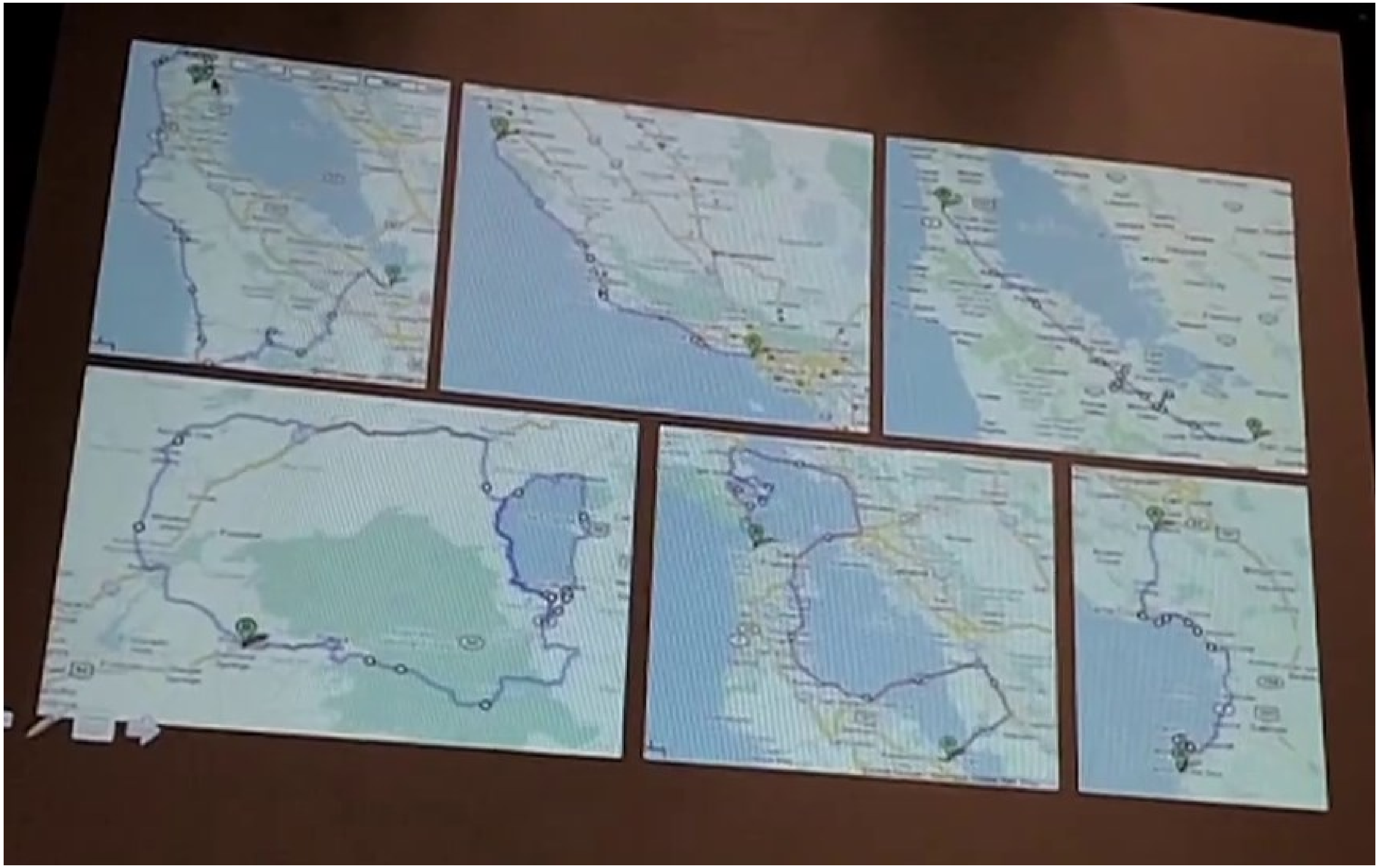
Mapping

- Stanley Laser Data – Beerbottle Pass
  - Link to video



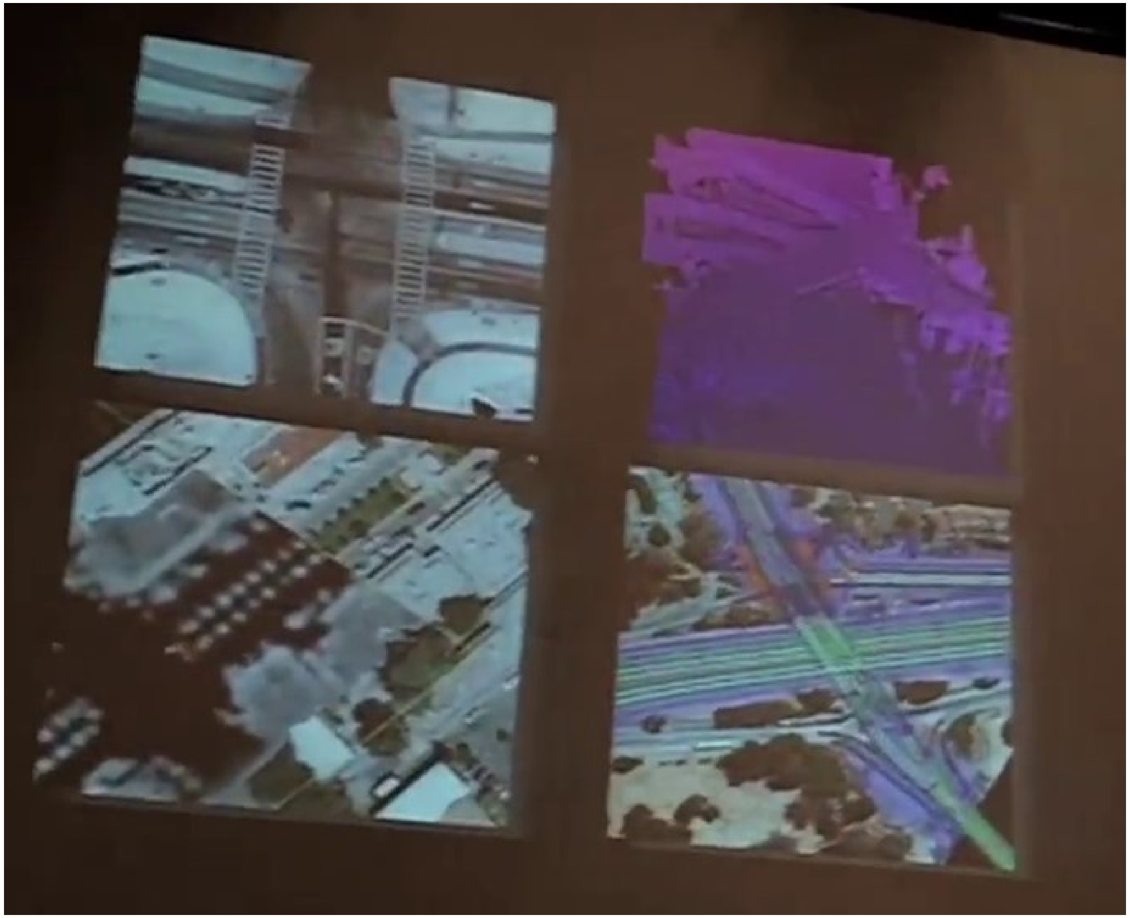
Mapping

- Google Car – 1000 mile challenge



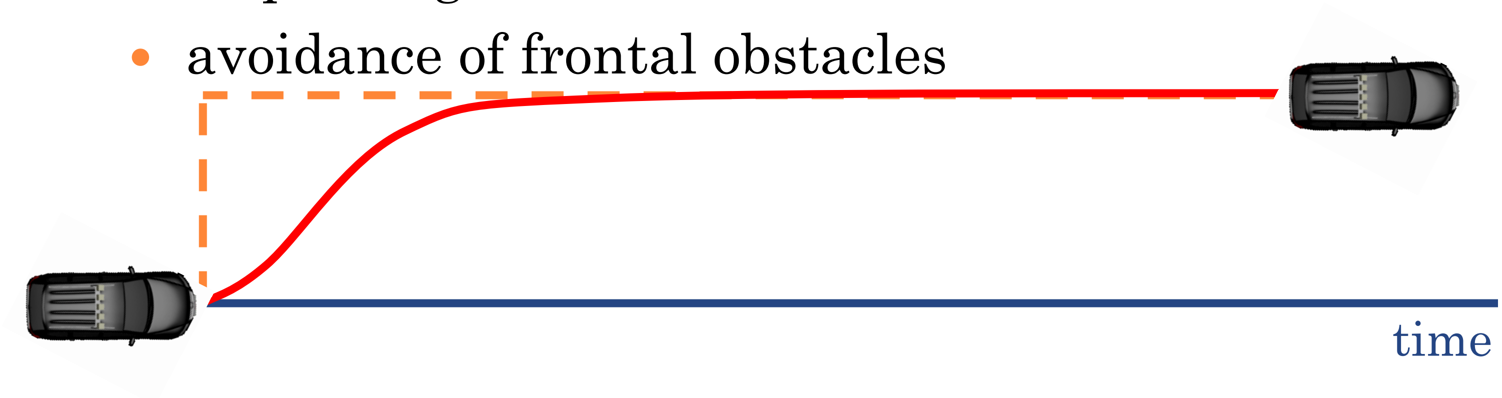
Mapping

- Google Car – 4 types of maps – 4:26

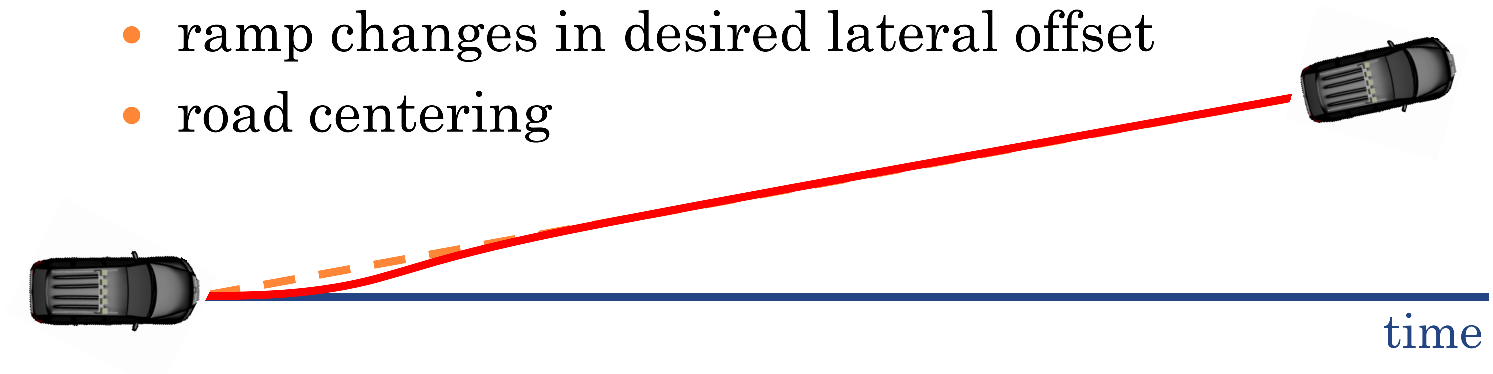


Stanley

- Path Planning – Parameterized search space
- Swerves
  - step changes in desired lateral offset
  - avoidance of frontal obstacles

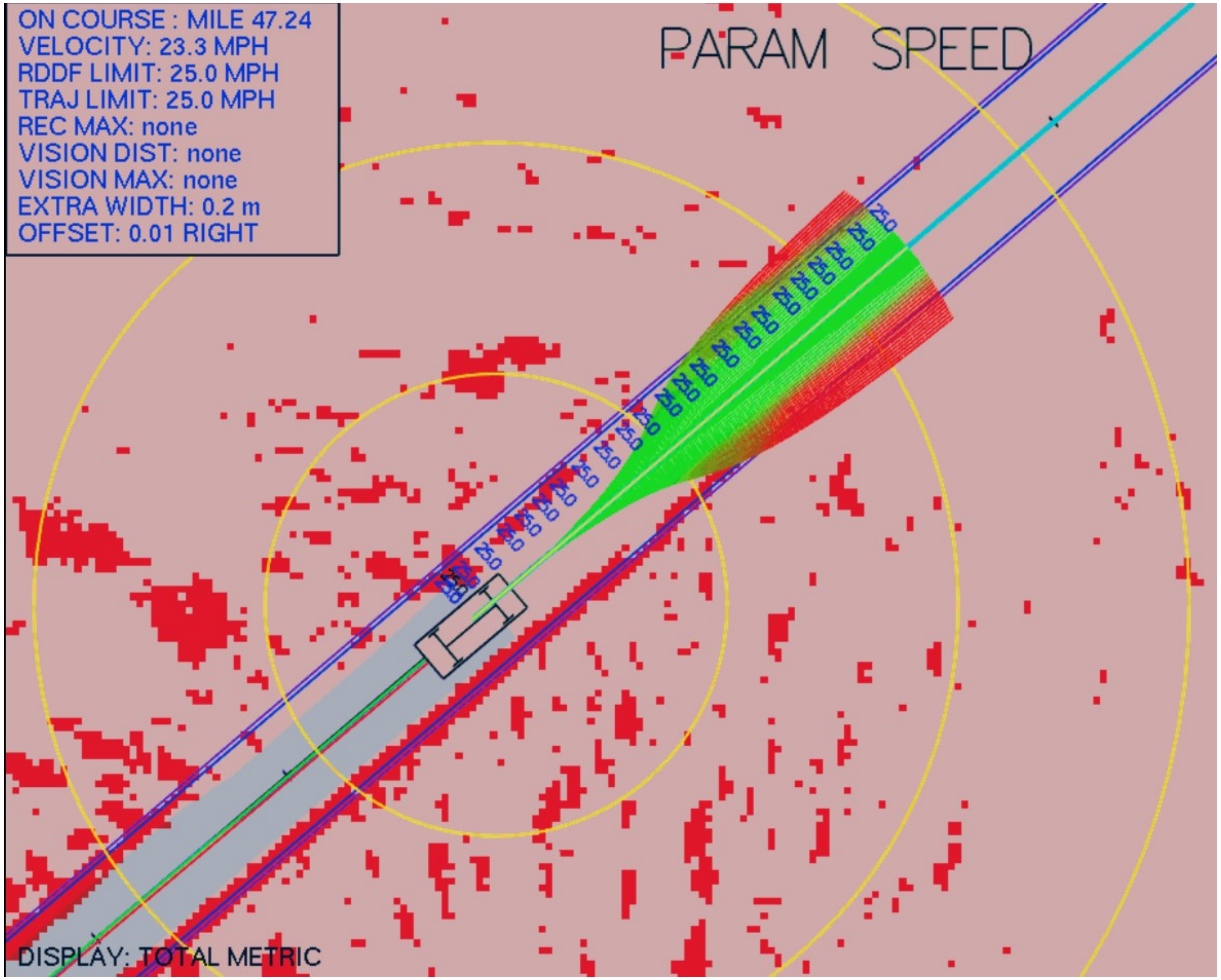


- Nudges
  - ramp changes in desired lateral offset
  - road centering



Stanley

- Path Planning on Stanley



Path Planning

- Stanley in Action

Trajectory Planning

- Google car video – 8:10

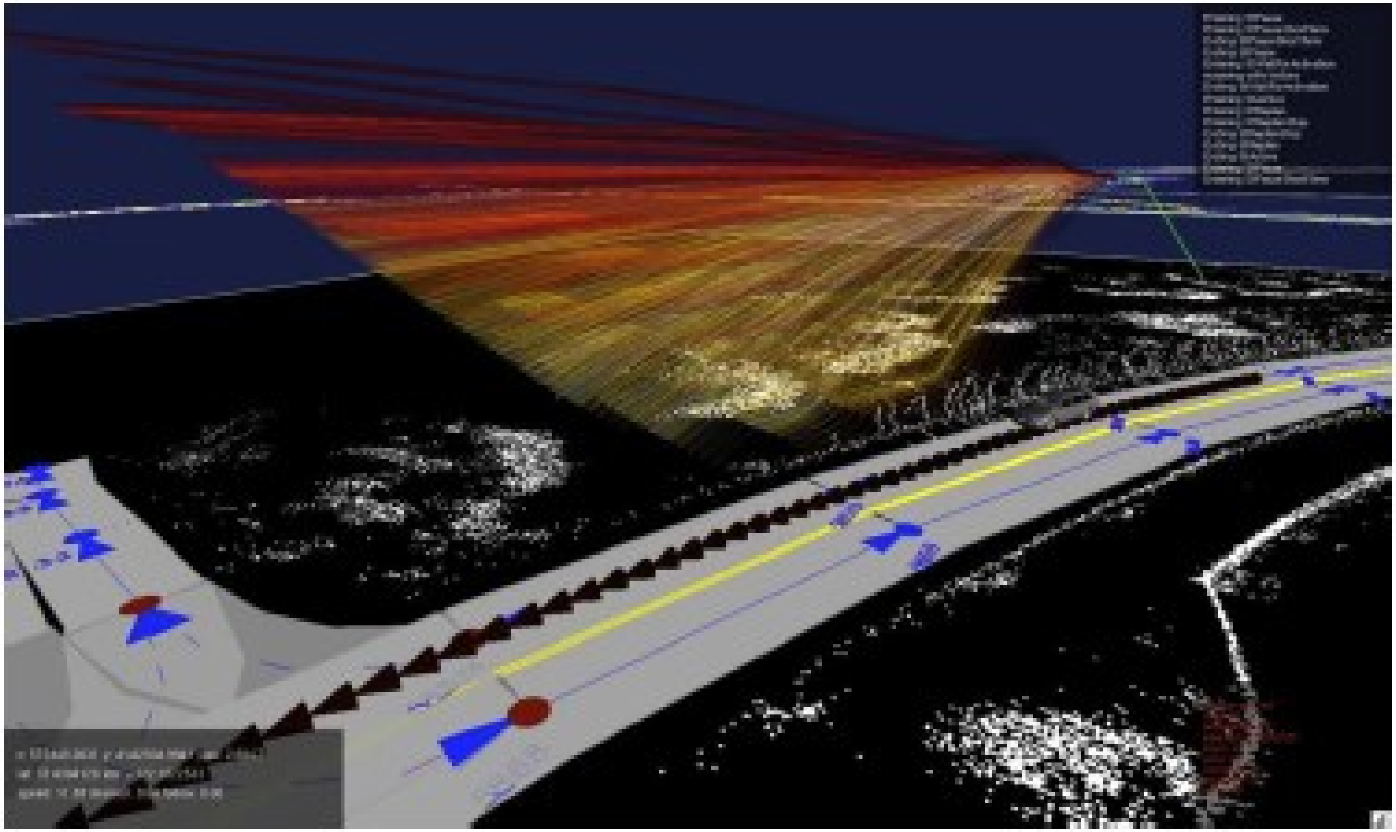


Fig. 6. Smooth trajectory set: The z axis shows the velocity; overall costs are indicated by the color.

Putting it all Together

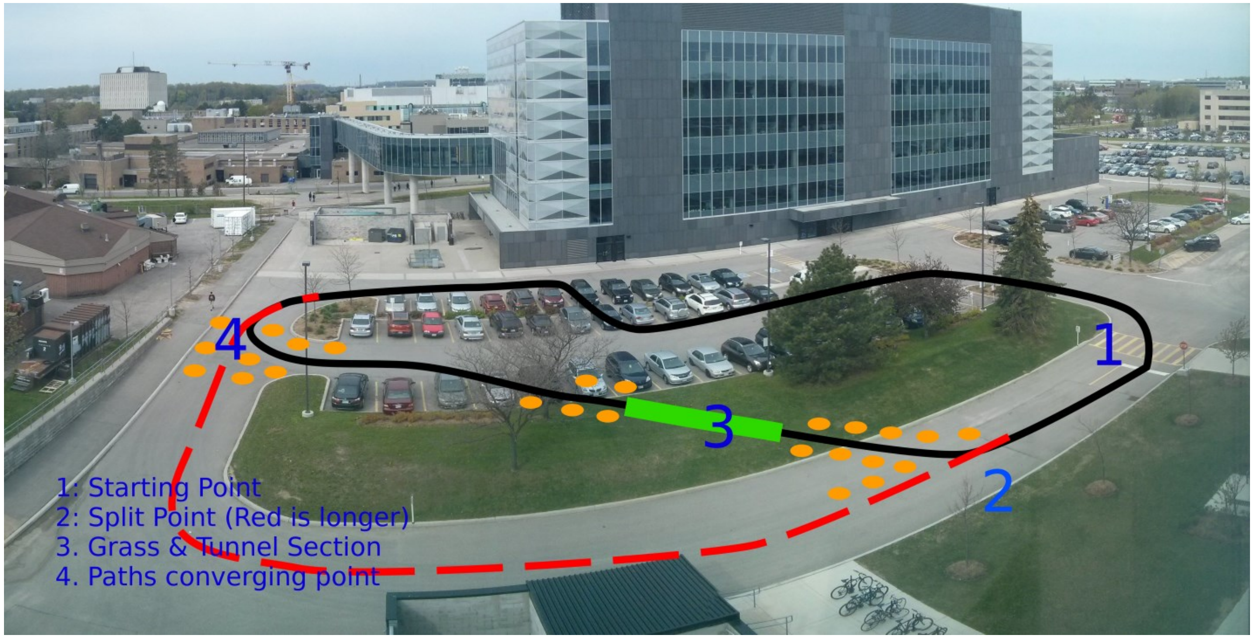
- Google Car – 9:05

IARRC - Robot Racing @ Waterloo

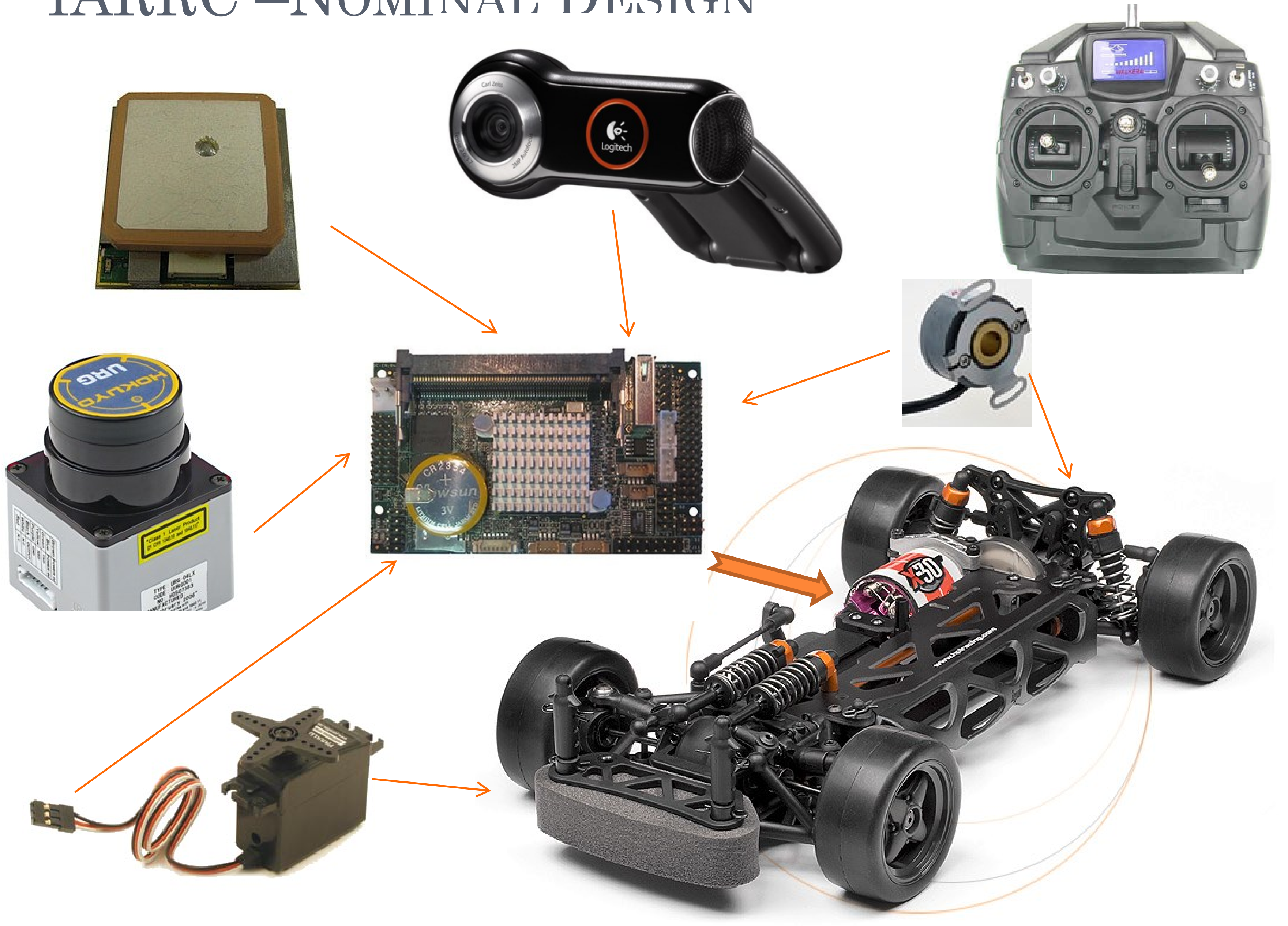
- Inaugural event organized by Mike Peasgood, April 2005, currently at Aeryon Labs Inc.
- 2014 back at Waterloo
- Focus shifting from pure speed to autonomy, perception at speed
- http://iarrc.ca

IARRC – Robot Racing

- Drag, Circuit and Design Events
- Circuit: 3 laps, ~250m loop, ~1.5-2m width
  - Tape Lines, Orange cone border
  - Tunnels, ramps
- Traffic light start signal
- Up to four competitors on course at the same time



IARRC –Nominal Design



2010 UW Autonomous Robot Racing Team

- Megalodon, followed by Lil' Turtle, link to video

2011 UW Autonomous Robot Racing Team

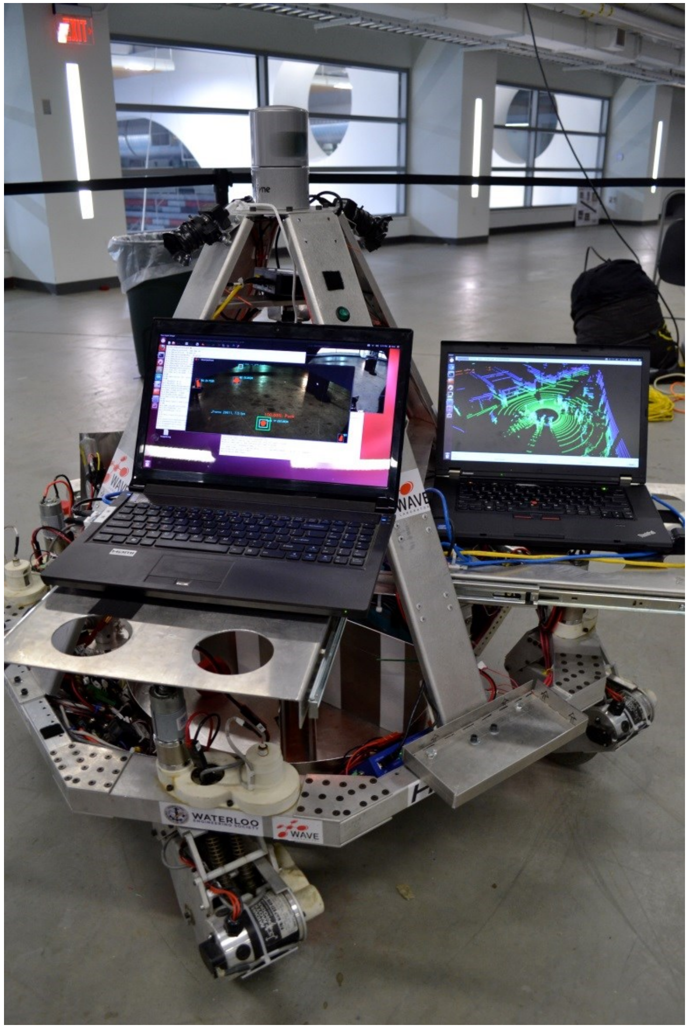
- Megalodon 2, sweeping the competition

2014 Competition Summary Video

- https://www.youtube.com/watch?v=yKtFLfoNgSY&feature=youtu.be

- Low res version

2012-14 NASA SAMPLE RETURN CHALLENGE



Mapping, Planning and Collection

In 2015, UWRT is going for three!

- 2015 International Ground Vehicle Competition
  - Because now we know we can win after going in 2014!
- 2015 International Autonomous Robot Racing Competition
  - Because we didn't win in 2014
- 2015 University Rover Challenge
  - Finally, after three years, we're ready to go
- Join us! uwroboticsteam@googlegroups.com
- Meeting tomorrow after class (5:30 Robotics Bay)
- http://robotics.uwaterloo.ca/

Extra Slides

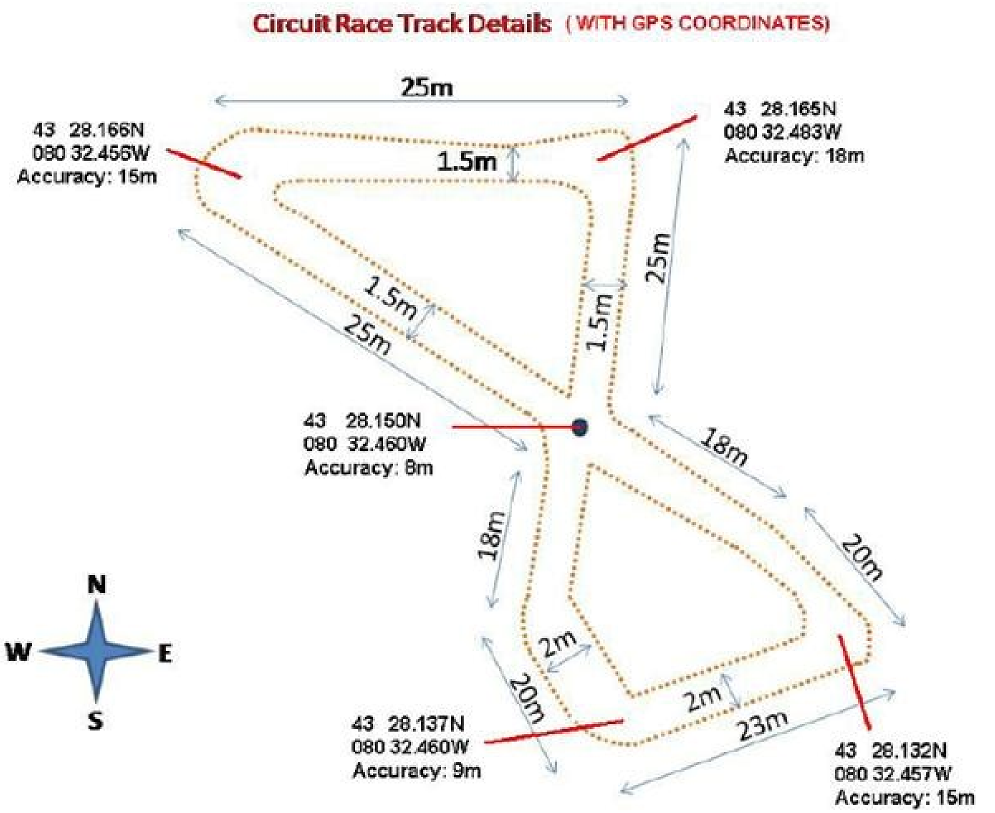
Stanley

- Vehicle
  - Volkswagen Touareg
  - 2.4L engine
  - 6-speed automatic transmission
  - Massively upgraded alternator to power on board electronics

- Actuation
  - Steer-by-wire control
  - Brake-by-wire control
  - Throttle-by-wire control
  - Manual override
  - 4WD managed by separate Volkswagen software

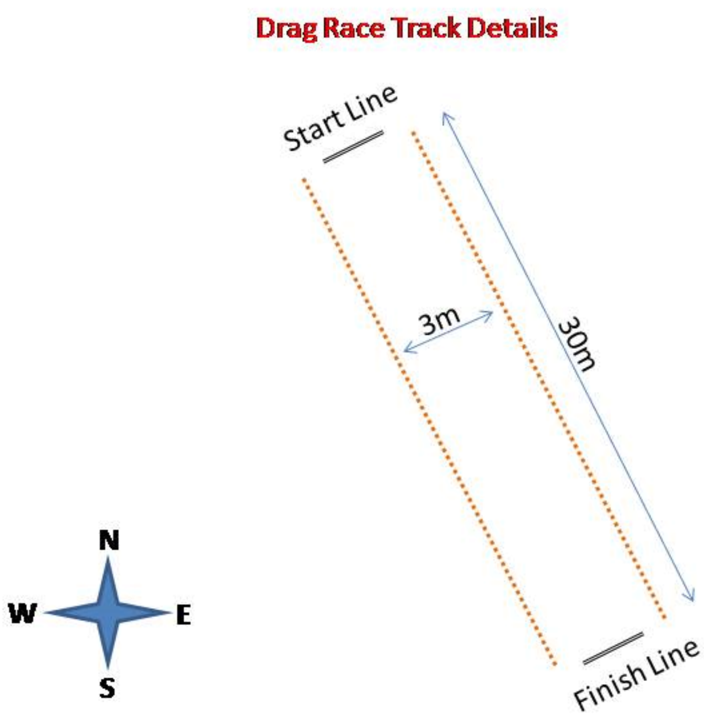
IARRC – Robot Racing Circuit

- Figure-8 circuit
- 3 laps
  - ~150m loop
  - ~1.5-2m width
  - Orange cone bord
  - Tunnels, ramps
- 4 competitors at a
- Pit-stops are allow
  as needed (up to 3



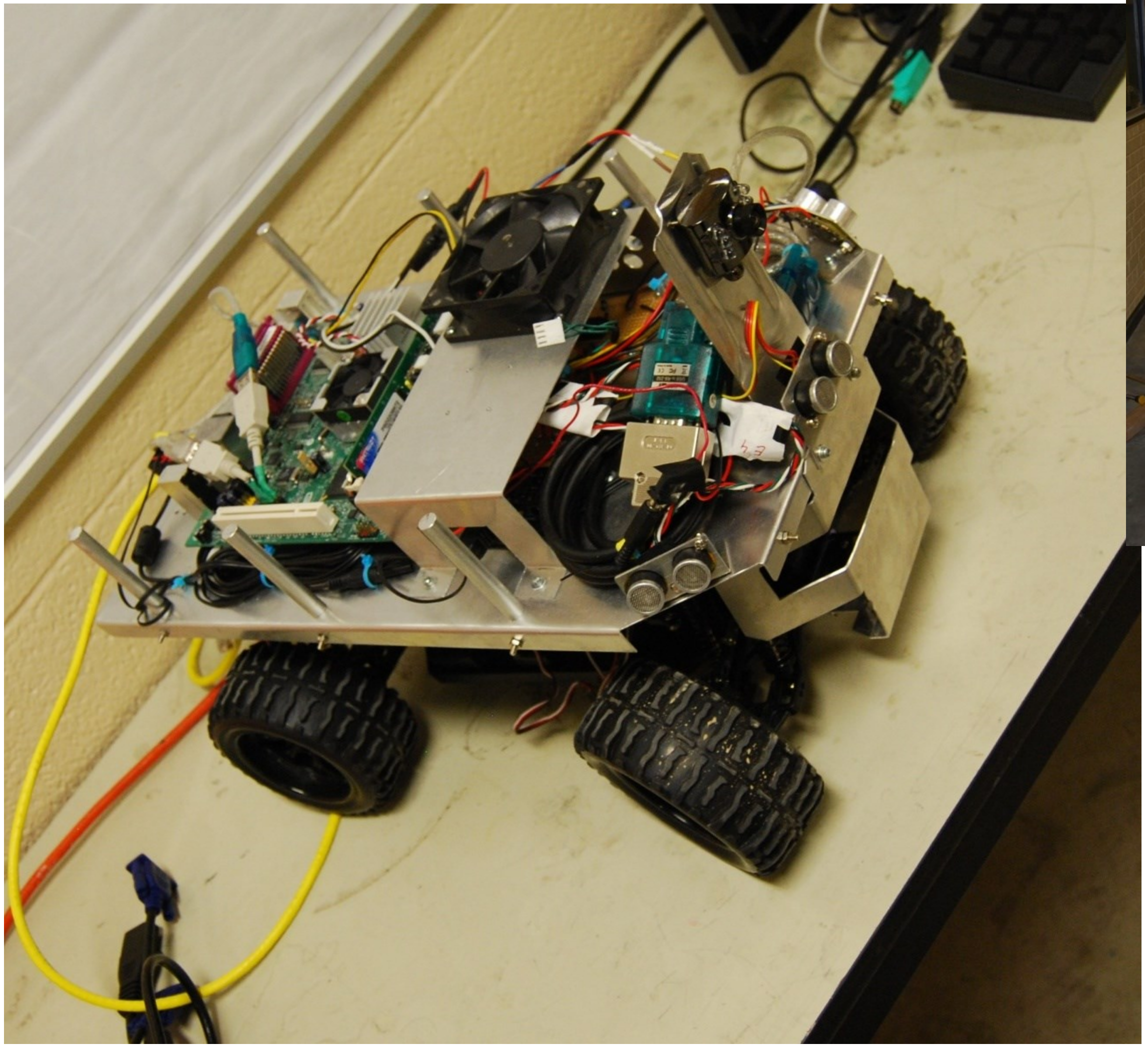
IARRC – Robot Racing Drag Race

- Head-to-head 30m sprint
- Cones on outside
- No barrier between lanes
- Collisions disqualify faulty



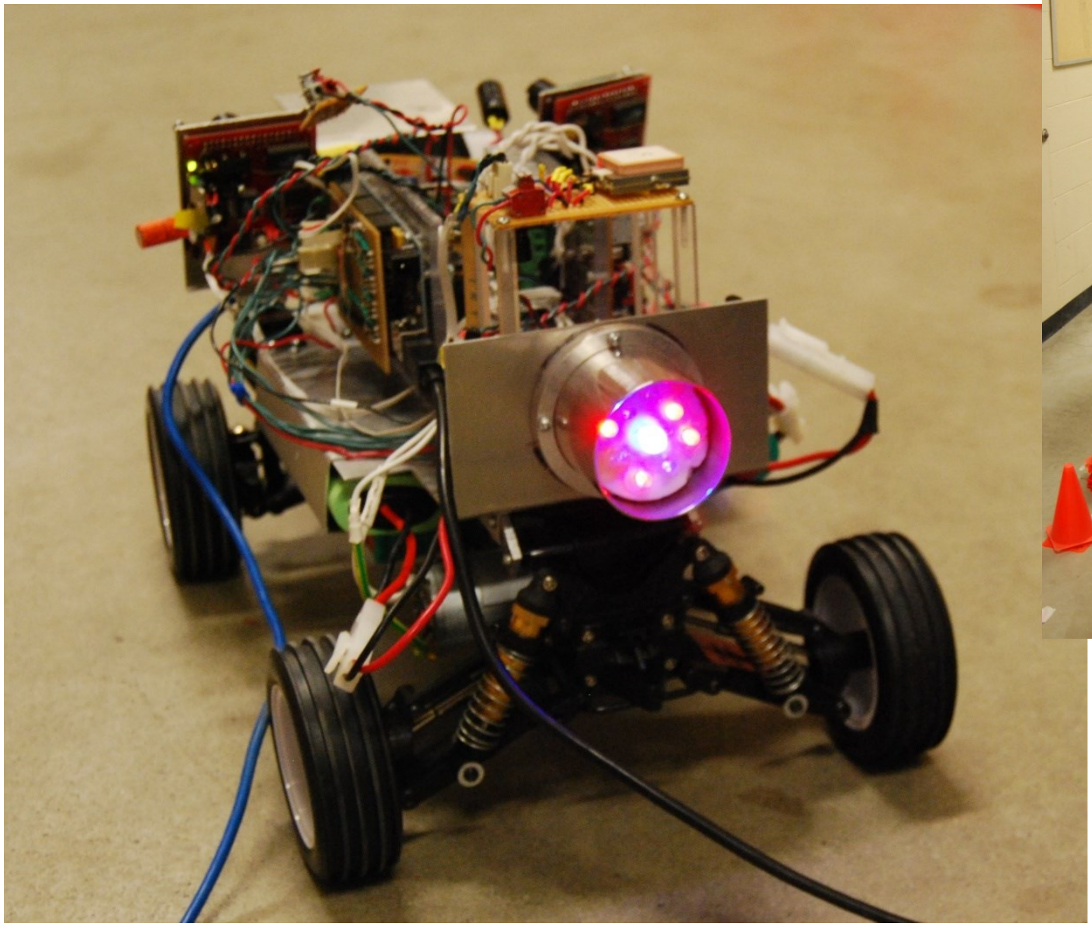
ME780 - Teams

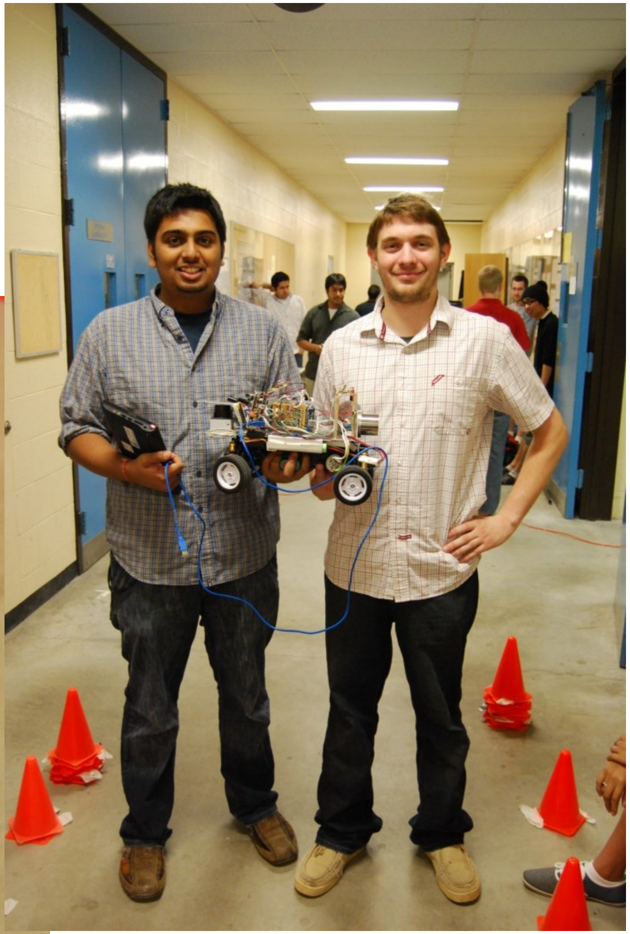
- Team Fujin



ME780 - Teams

- Team Neurobot





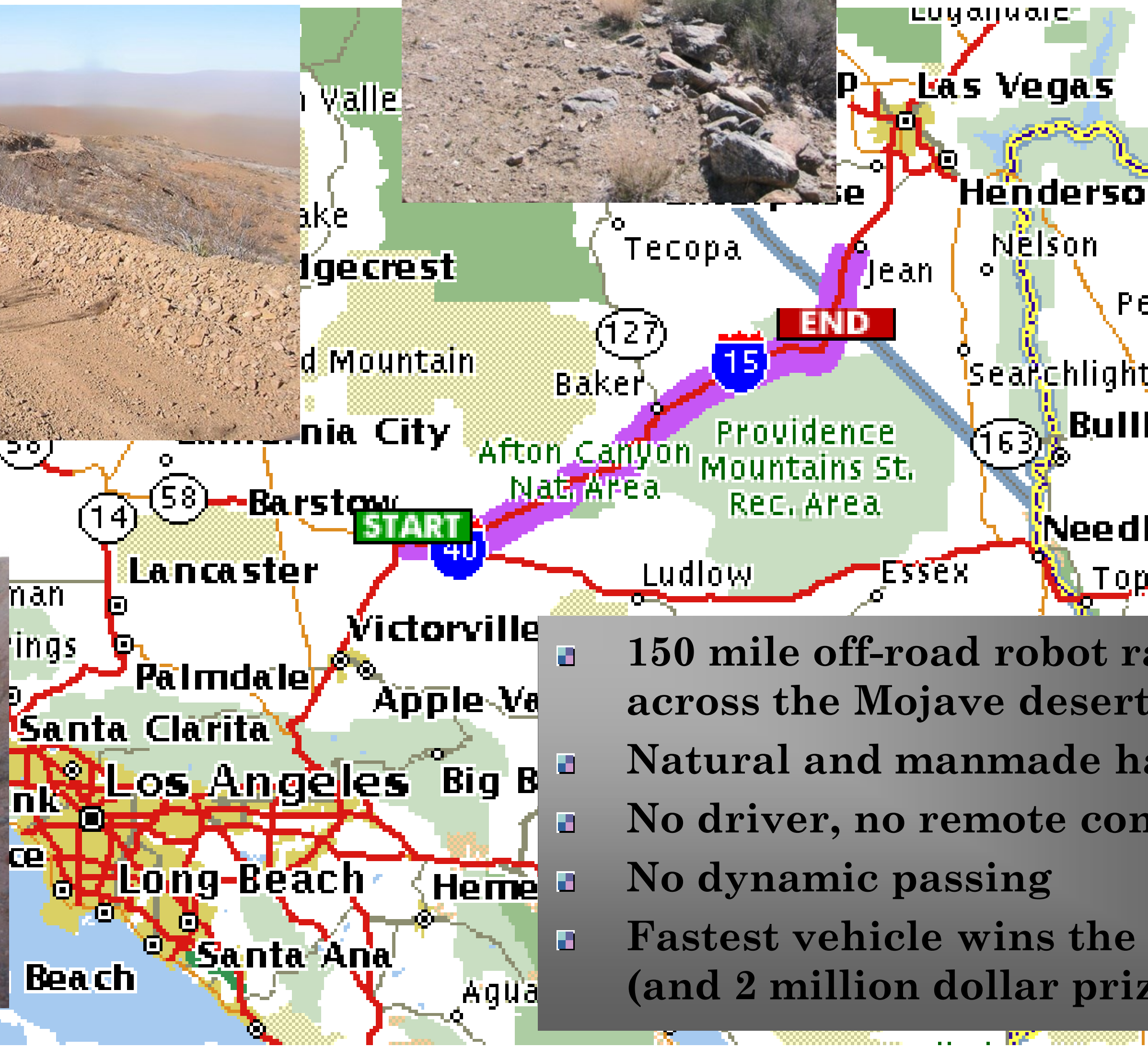
ME780 - Teams

- The A-Team

2012 NASA SAMPLE RETURN CHALLENGE

STANLEY

- Mission (2004)



- 150 mile off-road robot race across the Mojave desert
- Natural and manmade hazards
- No driver, no remote control
- No dynamic passing
- Fastest vehicle wins the race (and 2 million dollar prize)

Stanley

- Lasers
  - Extremely sensitive to vehicle attitude errors

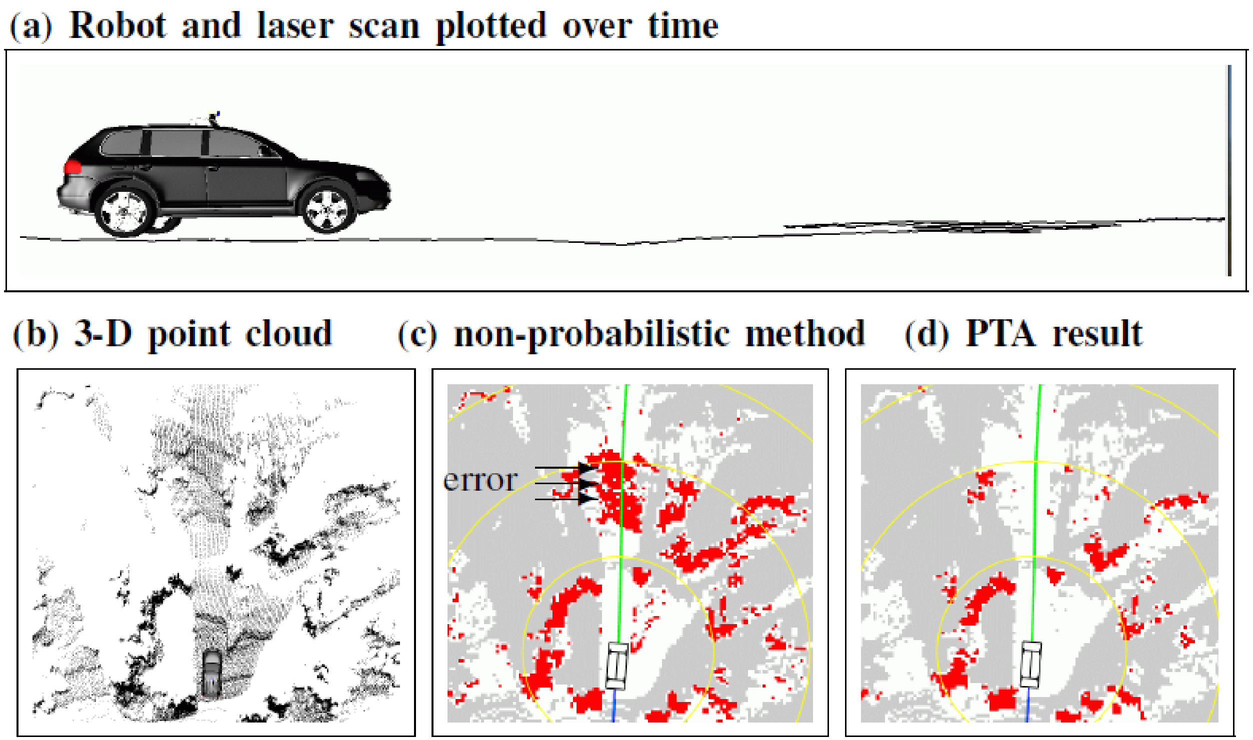


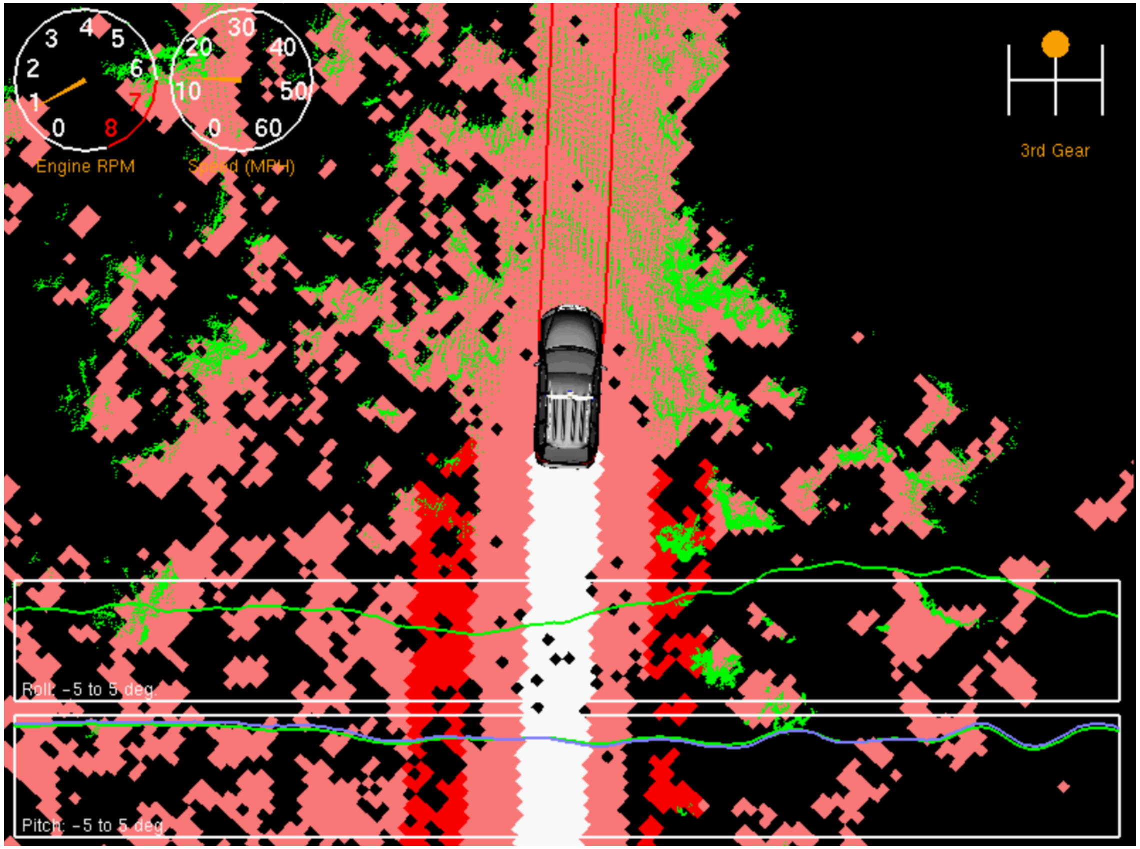
Figure 7. Comparison of non-probabilistic algorithm and PTA: (a) shows a scan over time, (b) the 3-D point cloud, (c) the erroneous map and (d) the result of PTA.

Stanley

- Mapping
  - Vision is notoriously hard to use to identify roadways

STANLEY

- Vision
  - Use when possible
  - Terrain Classification using laser data, [link to video]



Stanley

- Vision
  - Link to video

Google Car

- http://www.youtube.com/watch?v=YXylqtEQ0tk