Project-Based Teaching: CS/EE/ME 75 and the DARPA Grand Challenge

Richard M. Murray

Control and Dynamical Systems
California Institute of Technology

http://team.caltech.edu
CS/EE/ME 75, 2004-05: Alice

Team Caltech
- 50 undergraduates for ~1 year
- Course credit through CS/EE/ME 75
- Summer team: 36 full time undergrads, 3 grad students + 2 faculty + 6 volunteers

Alice
- 2005 Ford E-350 Van
- Sportsmobile 4x4 offroad package
- 5 cameras: 2 stereo pairs + roadfinding
- 5 LADARs: long, med*2, short, bumper
- 2 GPS units + 1 IMU (LN 200)
- 4 seats w/ computer workstations
- 6 P4, 3 GHz computers
- 1 AMD64 quad
Outline

I. CS/EE/ME 75: Introduction to Multi-Disciplinary Systems Engineering

II. Class Project: DARPA Grand Challenge

III. Lessons Learned and Discussion
CS/EE/ME 75: Multi-Disciplinary Systems Engineering

Course Goals

- Provide an introduction to team-based multi-disciplinary engineering
- Introduce tools for coordinating work across a large group of engineers
- Design, build and document a complex engineering system

Approach

- Select a major project each year (ideally with some prize money)
- Link work in individual classes to CS/EE/ME 75 project
- First two terms focused on design (through individual classes)
- Bring entire team together third term (and summer) to complete the project

Features

- Potential to provide integrating project across multiple depts (linked to courses)
- Participation across skill levels (Fr to Sr)
What We Teach

Project Planning Tools
• How do you plan and execute a large, complex project?
• Timeline charts (milestones)
• GOTChA charts - goals, objectives, technical challenges, approach

Project Management Tools
• Documentation - wiki
• Task tracking - bugzilla
• Code management - subversion, YaM

Decision Making
• Let students make the decisions on the decision (with lots of questions)
• Allow mistakes (best way to learn!)

Modeling and Testing
• Simulations, data logging & analysis
Team Structure

Project Manager
1 FTE Postdoc

Team Leader
Richard Murray
Joel Burdick

Integrated Product Team

Operations
Dominic Rizzo
- Computer modeling
- Test infrastructure
- Data logging/analysis
- Vehicle hardware

Navigation
Noel duToit
- Mission planner
- Traffic planning
- Path planning
- Trajectory tracking

Sensing
Pete Trautman
- Sensor HW/SW
- Mapping database
- Attention and pointing
- Sensor replay

Mission
Nok Wongpiromsarn
- Systems/SW engineering
- Goal/contingency mgmt
- Process management
- System health

System Administration

Simulation
All teams represented

Technical Advisors and Partners

Race teams
- Main working groups of the project; led by TA
- 2006-07: includes Fr through Gx through JPL

Infrastructure/cross-cutting teams
- Build/maintain project-level technology
The “Classroom”

Non-traditional classroom setting
• Lots of small group meetings
• Interaction in the shop and out in the field
• Interaction with race officials (DARPA)

Challenges
• Lots of work in the evenings and on weekends
2007 DARPA Grand Challenge (Urban Challenge)

**Autonomous Urban Driving**

- 60 mile course, less than 6 hours
- City streets, obeying traffic rules
- Follow cars, maintain safe distance
- Pull around stopped, moving vehicles
- Stop and go through intersections
- Navigate in parking lots (w/ other cars)
- U turns, traffic merges, replanning
- Prizes: $2M, $1M, $500K
Urban Driving

Video from 29 Jun 06 field test
- Front and side views from Tosin
- Rendered at 320x240, 15 Hz
- Manually synchronized

Some challenges
- Moving obstacle detection, separation, tracking and prediction
- Decision-making
- Lane markings (w/ shadows)
Team Caltech, 2006-07

Goal: design, build and document an autonomous ground vehicle that can win the 2007 Urban Challenge

Conceive
- Conceptual Design & Technology Analysis
- Autonomous Vehicles SURF (15)

Design
- CS 11
- CDS 110a
- EE/CS 148

Implement
- CS 11
- CDS 110b
- ME/CS 132

Optimize
- CS/EE/ME 75 (3-9-6)
- DGC SURF (12-24)

Independent Research/Senior Thesis Projects

Graduate Research
- Work Study students
- JPL/NGC + volunteers

25 Sep 06

CPET, Jan 07 R. Murray, Caltech
Key technical areas (focus of new research)

- Reasoning: decision making in presence of uncertainty
- Sensing technologies: characterization, detection, tracking, fusion
- Planning technologies: route, traffic, path
Mapping and Planning

Segment M

- Lane M.1
- Lane M.2

RNDF

dRNDF

1. eplan leading to intersection (stops at end)
2. eplan for executing turn (initiated after stop + car check)
3. eplan for parking zone
4. new eplan after detecting roadblock

travel direction

omnidirectional travel

roadblock

4. initial eplan to checkpoint

CNSE Retreat, 7 Oct 06
Richard M. Murray, Caltech CDS
Project Timeline

1 Oct 06 | 1 Jan 07 | 1 Apr 07 | 1 Jul 07 | 1 Oct 07
---|---|---|---|---
1. **Program Mgmt**
   - System specs
   - Program mgmt
   - Rev specs R1
   - Rev plan R2
   - Down-select R3
   - Select R4

2. **Navigation**
   - State estimation
   - Traj generation
   - Obst avoidance
   - Integ. new INS HW
   - Plan w/ traf constraints
   - Planning with moving obstacles

3. **Sensing**
   - Sensing HW/SW
   - Sensor fusion
   - Situat'l awareness
   - Integ. new sensor HW
   - Detection and tracking of moving obstacles (DATMO)
   - Uncertainty estimation
   - Multi-layer, 360° sensor coverage/fusion
   - Distributed sensor fusion and situational awareness

4. **Reasoning**
   - Tactical planning
   - Contingency mgmt
   - Learning/adapt'n
   - Basic traffic tactical plnr
   - Decision layer engine
   - Adv. traffic tactical plnr
   - Reasoning with uncertainty

5. **Sim/Testing**
   - Simulation
   - Data logging/playbk
   - Test process/eval
   - Traffic-level simulation LL
   - Sensor-based sims LL
   - Stochastic sims LL
   - Enhanced data logging
   - D1: basic nav/traf
   - D2: adv nav/traf
   - D3: 60 mi, w/ stops
   - D4: Biweekly Field Tests
   - DARPA M1: Kickoff
   - M2: Site visit NQE (M3, M4)
   - UFE (M5, M6)

Team Caltech, 18 Oct 06
Richard M. Murray, Caltech CDS
2006-07 Team Caltech

Race Teams

- Instr: Richard Murray
  - Coord: Dominic Rizzo

Operations Team
- Ken Fisher+
- R Grogan+*
- Daniel Alvarez
- Arthur Chang
- Iain Cranston*
- Matthew Feldman*
- Nicholas Fettie*
- Noelle Norris*
- Glenn Wagner
- Albert Wu
  - (Johnny Zhang)+
- William David Carrillo*
- Jimmy Paulos?
- Daniel Talancon?

Navigation Team
- Stefano di Carano
- Vanessa Carson
- Lars Creman
- Melvin Flores
  - (Sam Pfister)
- Tom Duong*
- Luke Durant*
- Jessica Gonzalez
- Ryan Lim
- Ghyn Loveness
- Russell Newman*
- Chris Schantz*
- Francisco Zabala
- David Waylonis*
- Steven Gray*
- Brent Goldman?
- Jerry He?
- Celia Peina?

Sensing Team
- Mohamed Aly
- Laura Lindzey+
- Jeremy Ma
- Sam Pfister
- Daniele Tarnino
- Justin McAllister
- Kenny Oslund
- Christopher Rasmussen
- Yi Wang
  - (Francisco Zabala)
- Johnny Zhang
- Joe McDonnell?
- Brandt Belson?
- Philipp Bootshofer?
- Miles Robinson?

Mission Team
- Vanessa Carson
- Aditya Khosla
- Scott Goodfriend
- Chase Stetson
- Josh Feingold
- Bob Rasmussen
- Michael Kaye
- Julia Braman?
- Edward Chen?
- Steve Chien?
- Jay Conrod
- Mitch Ingham?

(secondary asgnmt)
* = CS/EE/ME 75
+ = paid position

4 faculty
6 JPL
1 PD
8 GRA
3 visitors
1 alum
29 UGs
52 members
Lessons Learned

Course Goals
✓ Provide an introduction to team-based multi-disciplinary engineering
✓ Introduce tools for coordinating work across a large group of engineers
✓ Design, build and document a complex engineering system

Things that worked particularly well
• Students were incredibly smart, responsible and fun to work with
• Students learned a lot about engineering (success and failures)

Things that could be improved
• Better integration into Caltech courses
• Better teaching of design tools
• More effective use of reviews
• Better use of modeling and simulation
• More participation by women (currently about 10-15%)

Challenges for this year
• Competition is much harder ⇒ more challenging to integrate undergraduates
**Summary**

**CS/EE/ME 75: great course for teaching engineering**
- Requires interaction between CS, EE, ME (and more)
- Learn about working in teams to tackle a truly hard problem

**Urban Challenge serves as a great course project**
- Requires system level approach
- Combination of implementation of known techniques and development of new research ideas

A lot of fun (especially if you like going without sleep…)

<table>
<thead>
<tr>
<th>CS 11</th>
<th>CDS 110a</th>
<th>EE 148</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS/EE/ME 75</td>
<td>CDS 110b</td>
<td>ME 132</td>
</tr>
</tbody>
</table>

SURF