CPS: Autonomous Driving in Urban Environments

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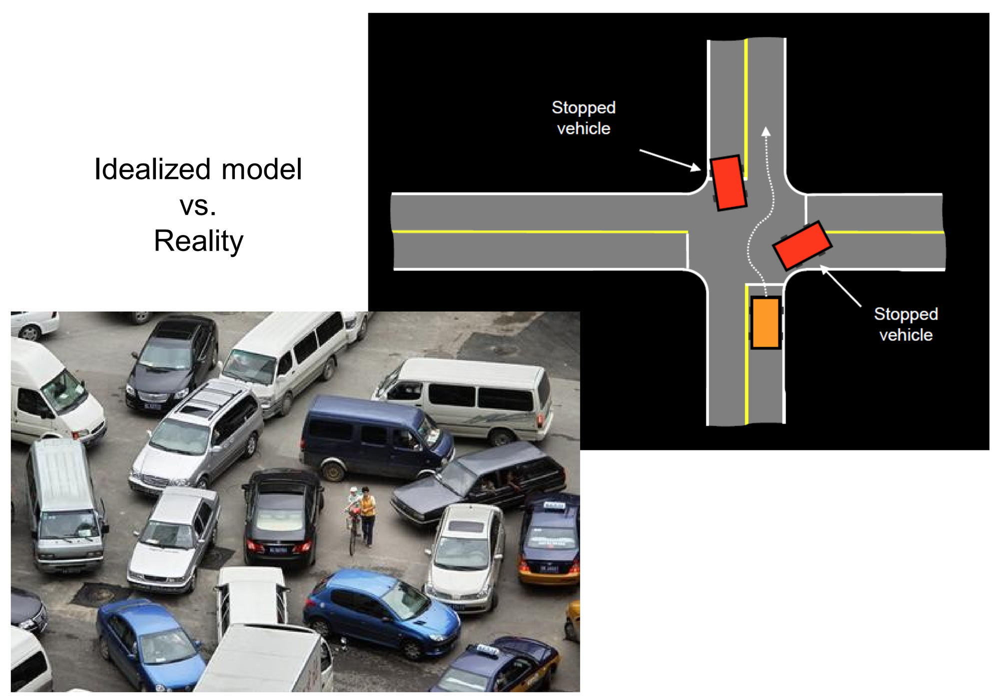
Introduction & Motivation

The specific application context driving our research is **autonomous vehicles operating safely in mixed-traffic urban environments.**

Such a car will be in a world where it interacts with other cars, humans, other external effects, and internal and external software modules. This is a prototypical CPS with which we have considerable experience over many years, including participation in the recent DARPA Urban Challenge.

Even in the latter case, though, operation to date has been restricted to relatively "clean" environments (such as multi-lane highways and simpler intersections with a few other vehicles).

Theoretical advances and new models are evaluated both by large-scale simulations, and by implementation on laboratory robots and road-worthy vehicles driven in real-world situations.



Computational Aspects

Real-time Computations for Autonomous Vehicles

- Feature extraction, clustering
- Mapping, localization, and transformations
- Route planning
- Dynamic Systems Computations
  - Kalman, and other filters
  - Linear and nonlinear control realizations
- Decision Systems, and Hybrid State System (HSS) Computations

Worst-Case Execution Time (WCET) Analysis

For hard real-time computations such as releasing the airbag, processing sensor information, etc., it is essential to know the WCET of tasks before scheduling them. Most of the previous work on WCET focuses primarily on caches whereas current processors adopt complex features like multi-level caches, out-of-order execution, pipelines, speculation, and multiple cores to improve performance. Our ongoing work focuses on establishing a mathematical model that includes these features for the analysis of WCET for state-of-the-art processors.

Fully Parallelized Particle Filters

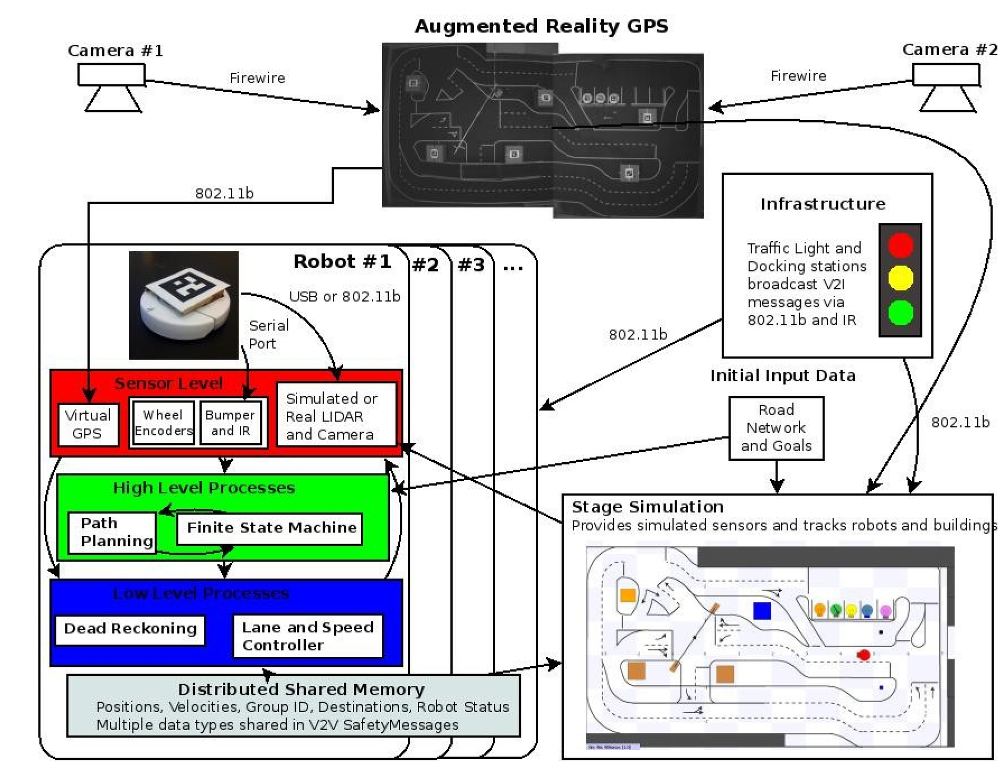
An autonomous vehicle needs signal processing techniques to detect from sensor data various events or time-varying signals such as the location of moving objects around it. If it is collaborating with other vehicles, it will also use data supplied by the other vehicles for evaluating its surroundings. We are using particle filters for such estimation problems. A particle filter consists of three steps: particle generation (sampling), computation of particle weights, and resampling. The resampling step is sequential for most existing algorithms and limits speedup. We have designed novel parallel resampling algorithms and are implementing them on existing multicore platforms such as graphic processing units (GPUs).

Simulator & Test Environments

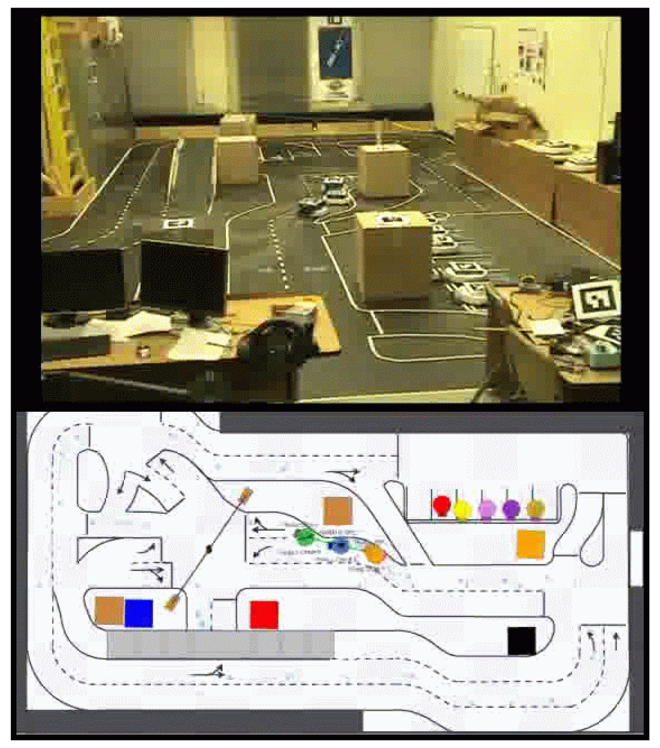
- Investigate uses for Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) for improving traffic flow
- Enable testing and verification of control software with simulation, mixed simulation and laboratory robots, and finally real vehicles
- Develop algorithms for path-planning, road finding, and vehicle cooperation in a controlled laboratory setting before testing outdoors

Indoor Testbed

- Multiple robots with mixed sensing capabilities
- Integrated hardware and virtual robots and sensors



Convoying Demonstration

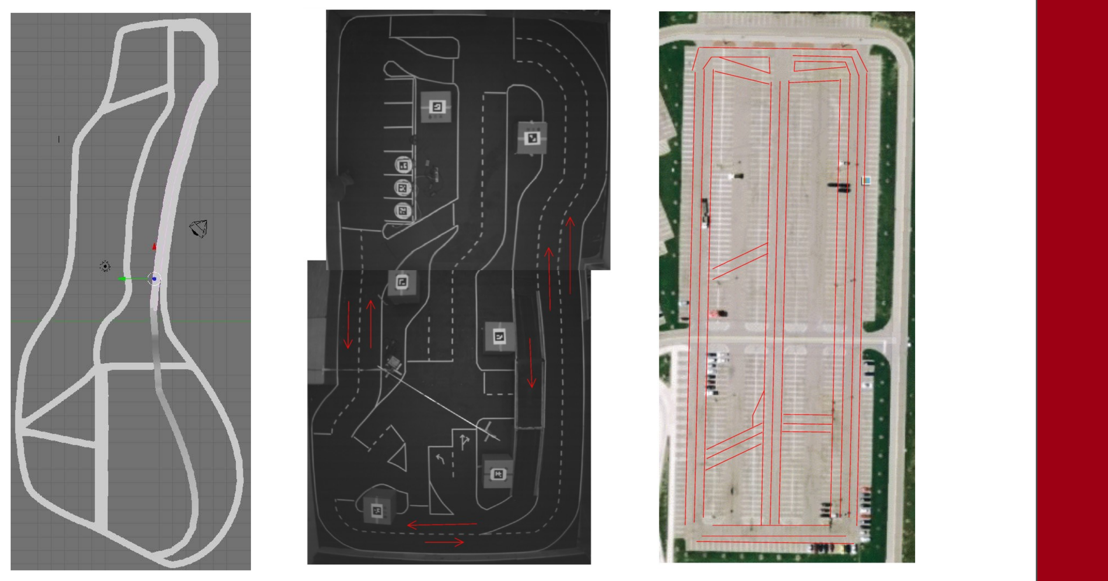


Automotive Testbed

- Multiple DSRC networked vehicles with various sensing and control capabilities

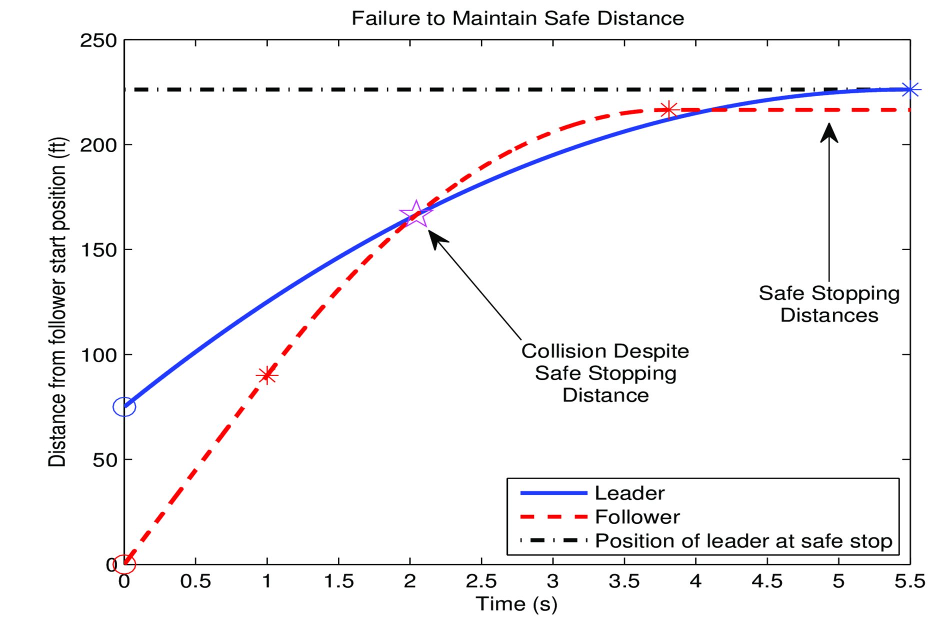
Topological Consistency for Development

- Simulation → Lab Testing → Full Testing



Verification of Smooth & Close Collision-Free Driving

Modern adaptive cruise control technologies are designed to improve the comfort or safety of the driver however, no safety guarantees are asserted by these designs. Furthermore, existing theoretical work in the safety verification of adaptive cruise control algorithms require both discrete braking modes and overly conservative separation distances to make such safety guarantees. Thus, existing work in safety verification both risks reducing driver comfort while also eliminating any of the performance gains typically associated with automated highways. We have preliminary work that extends verification of automated highway systems to mitigate both of these problems.



Capitalizing on our group's experience with optimal control and verification of software systems, we have developed safety conditions for adaptive cruise control algorithms that do not require discontinuous braking and also allow for substantially lower following distances than existing work in the verification of autonomous highway systems.

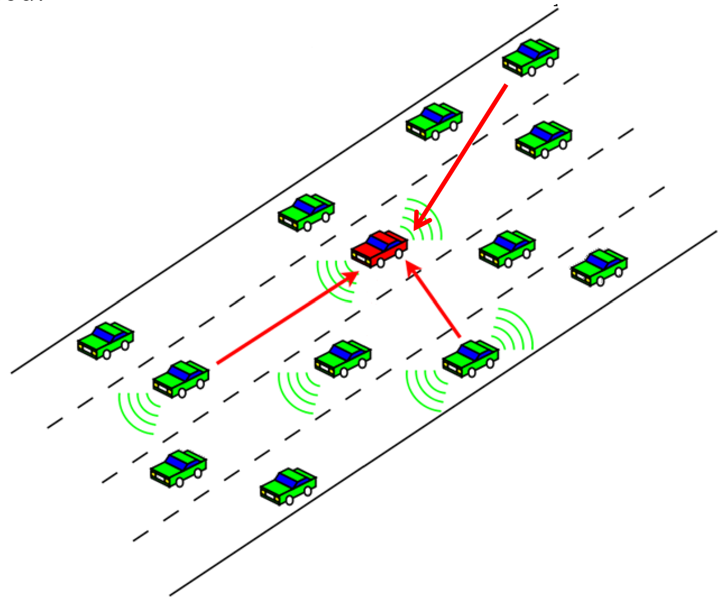
Collaborative Driving

2011 GCDC

Investigation on collaborative driving, specifically in convoy type applications, has continued. Hybrid system models of the scenarios in the Grand Cooperative Driving Challenge (GCDC), were developed and simulated. We supported Team MEKAR from Turkey in a Consortium that involved ITU and Okan University in the GCDC organized by TNO in the Netherlands in May 2011.

Networked sensing for collaborating mobile platforms

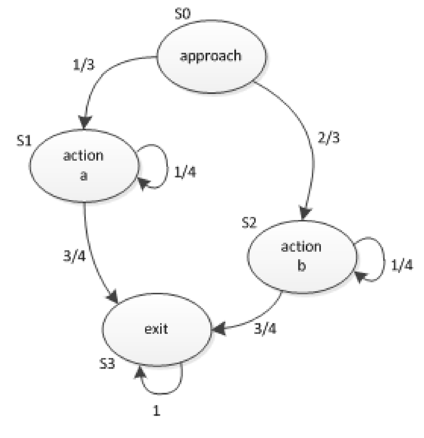
We have started investigating an (urban or highway) dense traffic configuration where an autonomous vehicle collaborates with only a small set of communicating vehicles, providing information on sensing of their surroundings. Thus, a dynamic map of the surroundings is constructed.



Estimation and Tracking in Complex, Mobile Environments

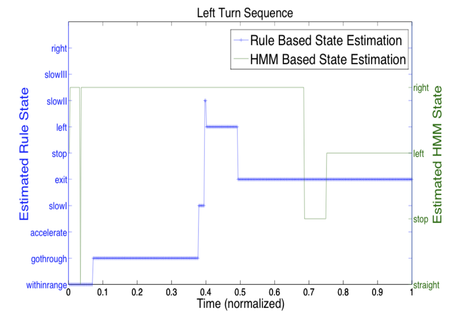
Driver Intent Modeling

Finite State machines with probabilistic transitions were developed for driver intent representations.

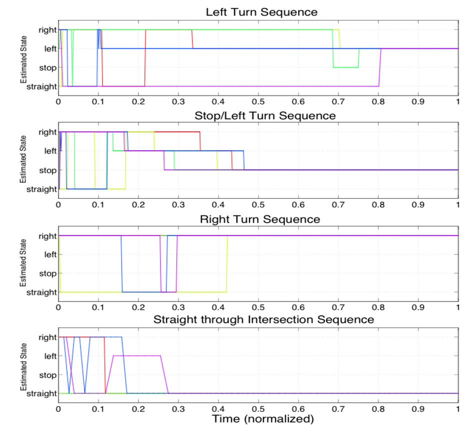


Behavior Estimation with Hidden Markov Models

A Hidden Markov Model approach was also developed for four tasks of a vehicle near an intersection: stopping, turning left, turning right, and continuing straight. Results from limited data show significant promise for the HMM based approach. The number of maneuvers and datasets will be expanded after further data collection using an instrumented test vehicle.



Rule-based vs. HMM-based Estimation for Left Turn Maneuvers



HMM State Estimation for 20 Vehicle Maneuvers

Acknowledgments

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For further information

Please contact *umit@ece.osu.edu* . More information on this and related projects can be obtained at *http://cps.osc.edu/*.

Control and Intelligent Transportation Research Lab CITR

Ohio Supercomputer Center

Magic 2010

Some members of the CPS group participated in the Multi Autonomous Ground-Robotic International Challenge (MAGIC) which considers CPS issues related to autonomous but cooperating mobile platforms in complex, partially known environments.

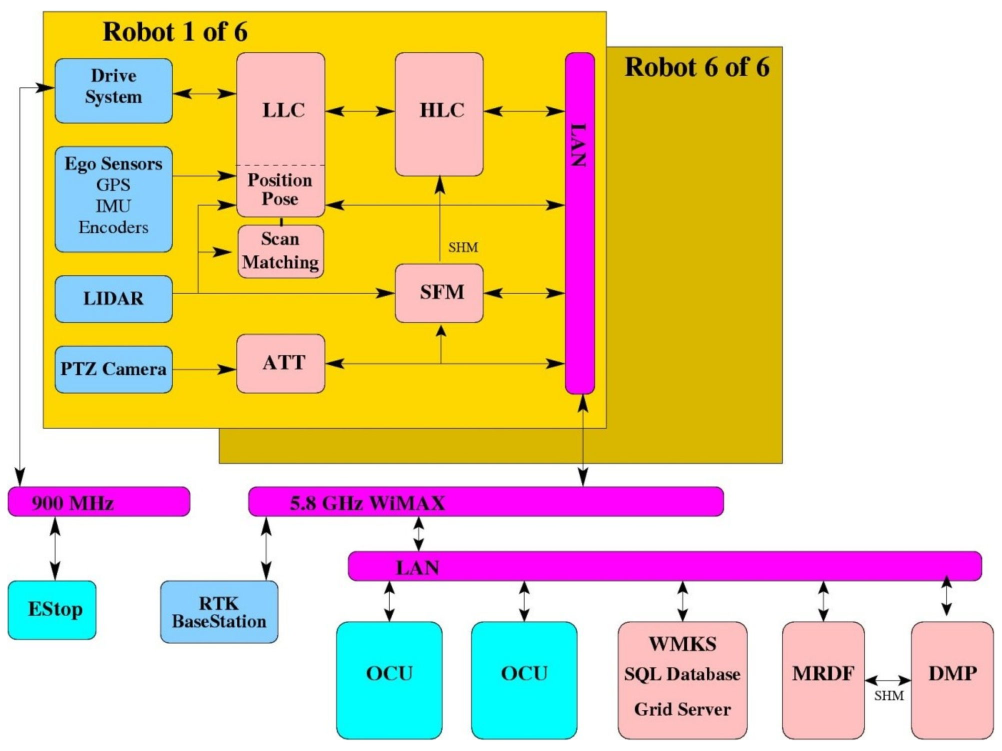
- Urban ISR (Intelligence, Surveillance, Reconnaissance) Mission
- Cooperative teams of autonomous ground vehicle systems
- Complete system must dynamically plan, coordinate, and execute tasks

Challenge

- Completely and accurately explore and map designated areas
- Recognize, classify, and locate simulated threats
- Function in outdoor and indoor (GPS denied) areas
- Provide operator interface, status information and collected data

Implementation and System Architecture

- Robotic platforms (propulsion, sensing, control, power)
- Communications network
- Ground stations (mapping and sensor fusion, database, planning, operator interface)



Development

Simulation → Indoor Testbed → Outdoor Testbed

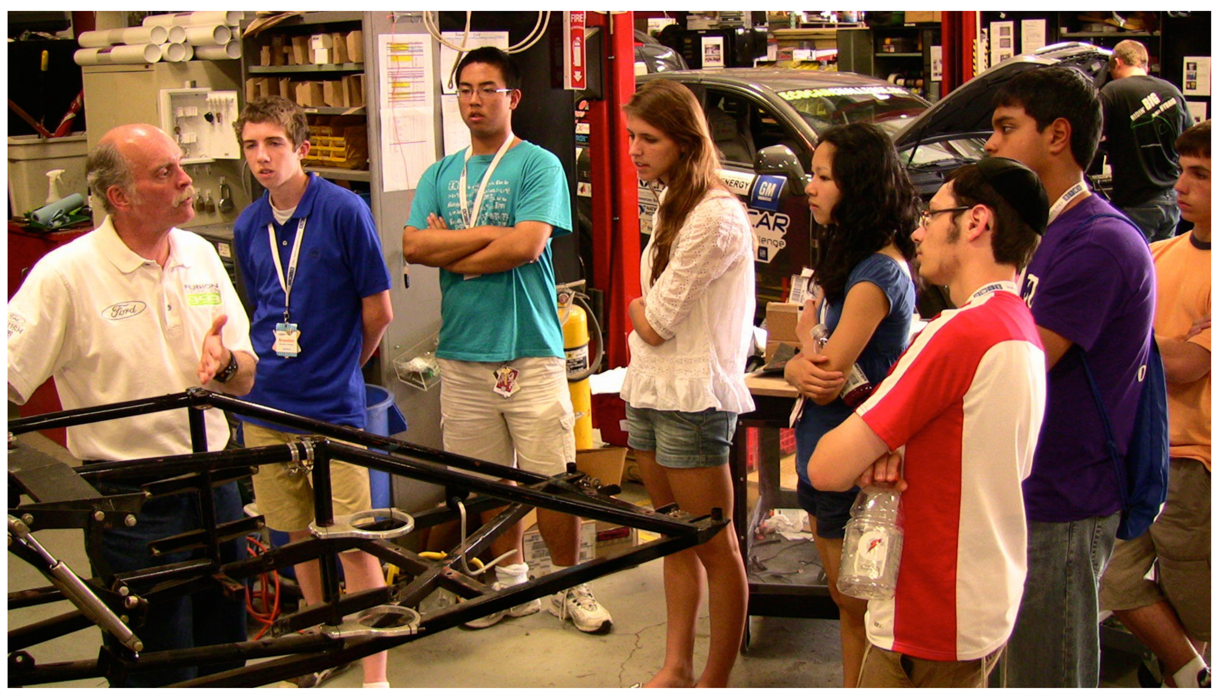
Graduate Students

- Emrah Adamey
- Ozan Basciftci
- Scott Biddlestone
- Lina Fu (09-10)
- Vijay Gadepally
- Peng Gong
- Arda Kurt
- Jaeyong Park
- Neil Sawant (09-10)
- Michael Vernier

Education: Teaching CPS to High School Students

Since 2010, the OSU CPS Group has supported a Program/Project in the Summer Institute organized by the Ohio Supercomputer Center (OSC). The Summer Institute is a two-week residential program designed to raise students' interest in STEM fields through a collaborative and dynamic research environment and hands on experience with the latest in cutting edge technology. In SI 2011, there were four separate projects, one of which was titled "Obstacle Avoidance Roomba."

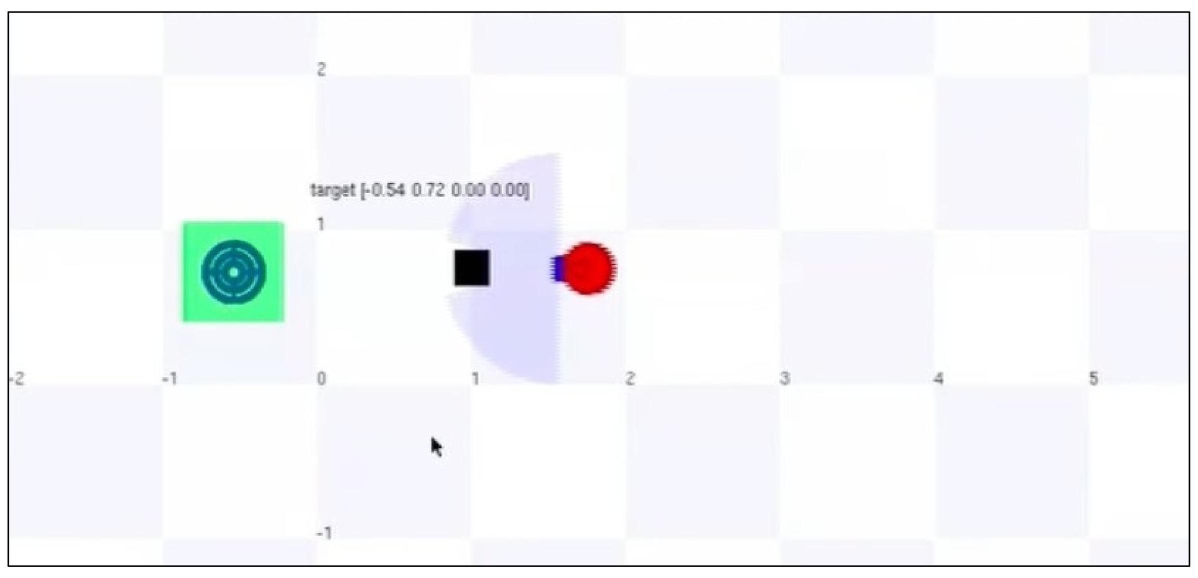
Apart from their projects, students also take part in science-related field trips, and team building exercises.



In order to teach CPS fundamentals, an "Obstacle Avoidance Roomba" project was designed by Vijay Gadepally, Arda Kurt, Scott Biddlestone, Michael Vernier, Ümit Özgüner, and Ashok Krishnamurthy. The project involved the design of algorithms and software that controlled a Roomba to avoid an obstacle. This project was divided into four parts:

- Follow coordinates entered by a user
- Acquire a target and plan an optimum path to the target
- Acquire a target and avoid a single obstacle to reach the target
- Acquire a target and avoid multiple obstacles to reach the target

Initial programming and testing of the software was done using the Player/Stage simulator package. Player is a network server for robot control that supports a variety of robot hardware of which the Roomba is one. Stage simulates a population of mobile robots, sensors and objects.



New Directions

- An NSF funded workshop on ITS-Energy was held at the Ohio State University on the topic of Intelligent Transportation Systems contribution to energy savings in road traffic was considered. CPS issues were specifically identified as relevant.
- A number of students were guided in Capstone Design Projects and extensions, specifically considering the utility of brain waves in understanding driver intent. An urban driving simulator was developed and traffic light violation scenarios were investigated.