How Robots Can Help Stop Global Warming

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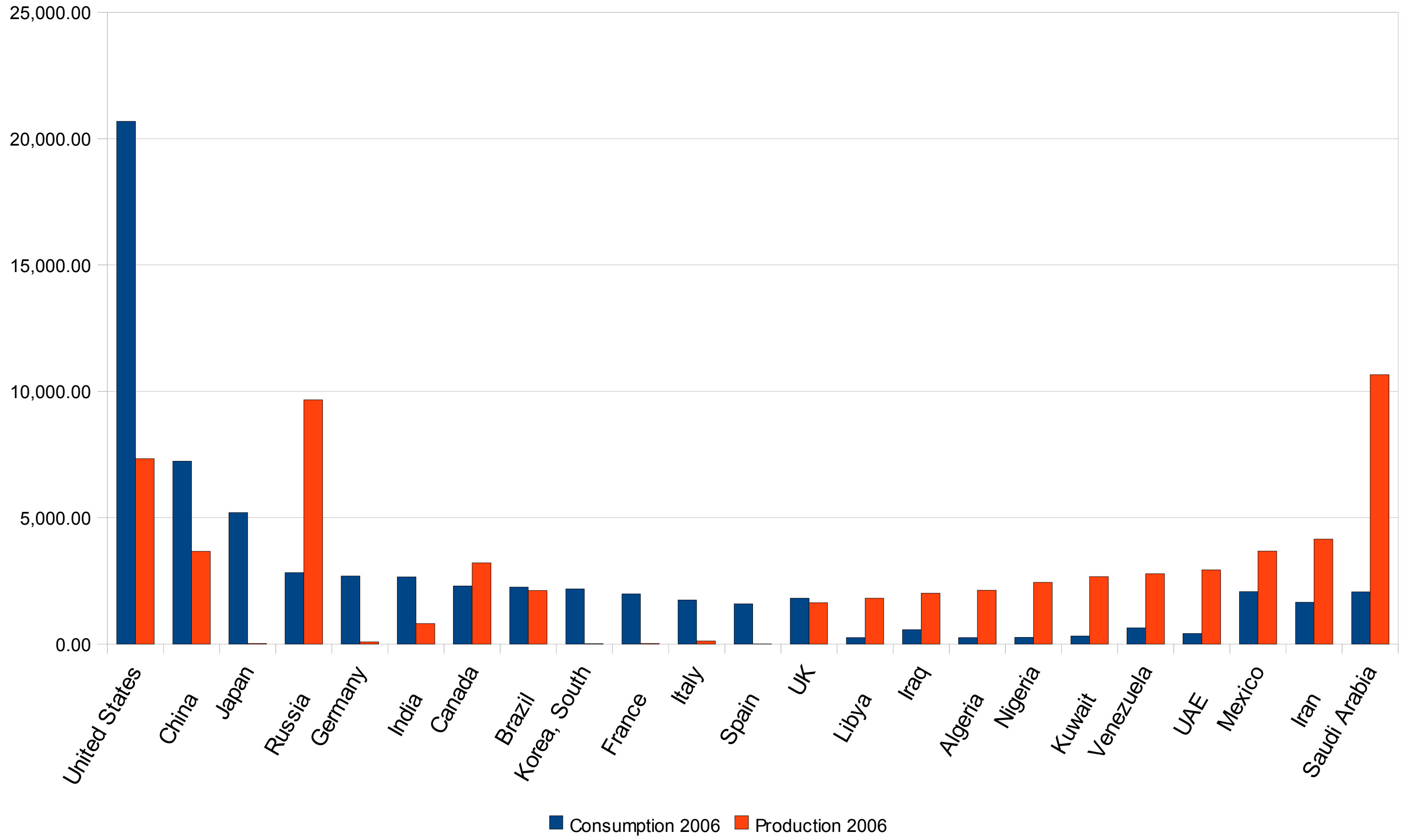
Outline

- Define the problem
- Examine technologies:
  - Autonomous vehicles
  - Personal rapid transit (PRT)
  - Energy optimized vehicles
- System design
- Prototype implementation

3 largest oil consumers exceed their production



http://www.eia.doe.gov/energyexplained

US Commuting Energy

Americans drive 5 trillion km annually.

Trips to the workplace account for 22.5% of US personal travel.

65% of miles are classified as urban.

This proposal could replace up to half of those urban km (1.7T km).

The energy savings would be 3M barrels of oil per day. This is 15% of US petroleum usage.

The carbon savings would be 146,000 metric tons per day. This is 12 trains of 100 cars of coal.

How Americans get to work

88% drive a car or light truck

- 76% drive alone and 12% carpool.

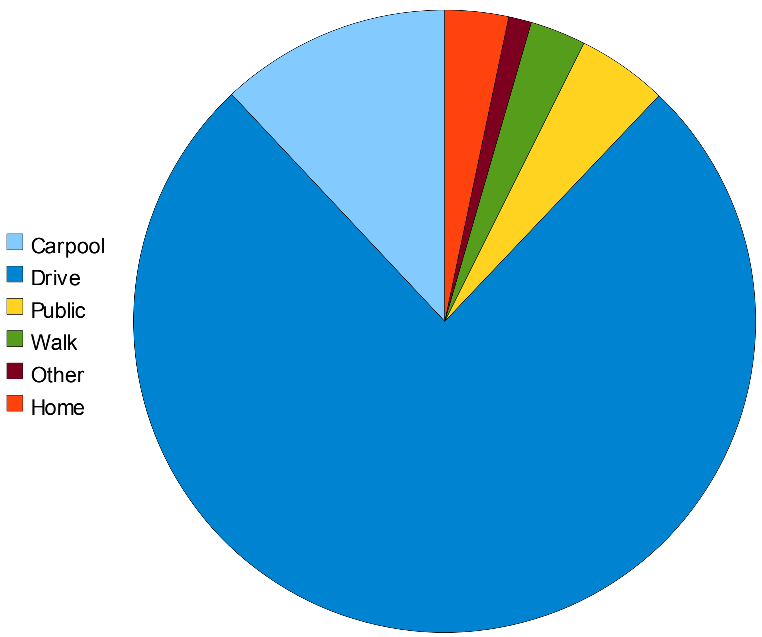
4.7% use public transportation

2.9% walk

3.3% work at home

1.2% use bicycle or motorcycle.

http://www.census.gov/population/www/socdemo/journey.html



Major Japanese cities move people effectively

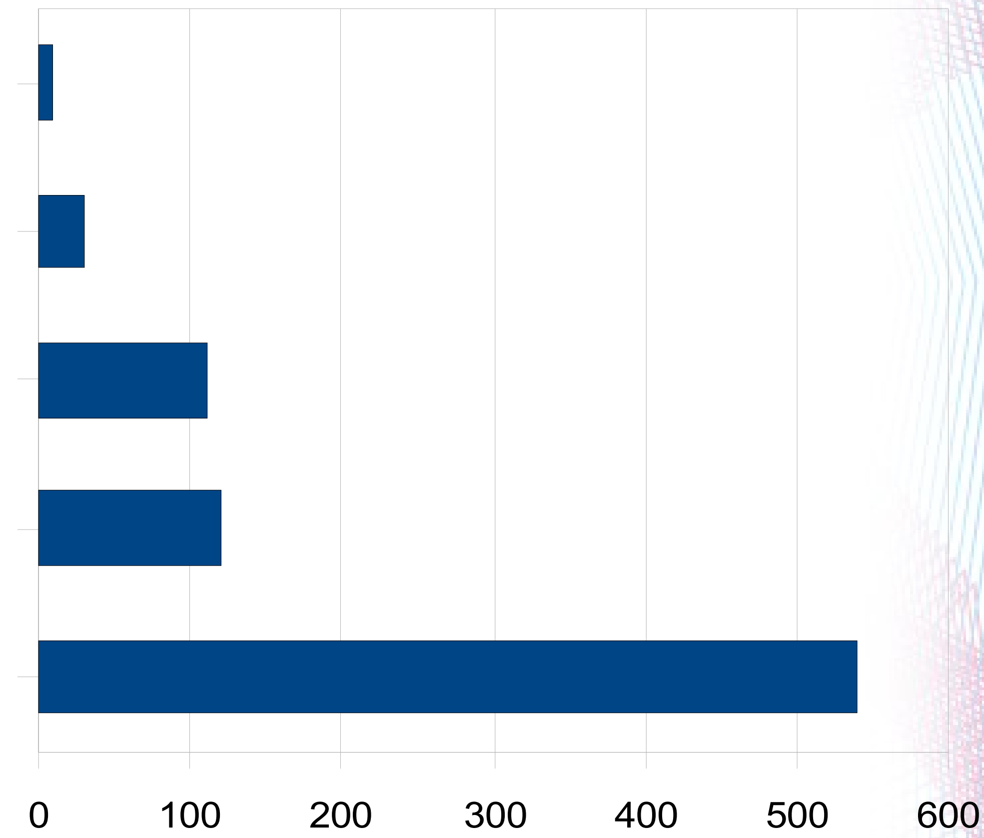
Tokyo is already well served by its metro system.

The proposed system is designed for medium sized cities that depend on cars and buses.

Proposed system uses single person, light, autonomous, electric pods.

Energy consumption at 50 kph (kcal/km/person)

- 11: 1-person Pod
- 30: Bicycle
- 112: Train & riders
- 120: Car & 5 riders
- 539: Car & driver (6.2 l/100 km)



D.G. Gordon & J. Papadopoulis, Bicycling Science, 3rd ed, MIT Press, 2004.
The HPV is an order of magnitude energy improvement over good solutions. It represents two orders of magnitude better energy use compared to many cars on the road today.

Objectives

- Improve energy efficiency by 10x to 30x.
- Eliminate all tailpipe emissions.
- Increase freeway lane capacity by 8x.
- Reduce traffic accidents by 20x to 40x.
- Eliminate congestion.
- Use existing infrastructure.
- Same performance as light rail at a fraction of the cost.

Vehicle math

- Power = $K_1 * V + K_2 * V^3$
- Power (W) is what is needed to hold the speed against rolling resistance and air drag.
- Assume smooth level surface and no wind.
- For a car, rolling resistance is dominant until 60 kph.
- For a light vehicle, air drag takes over at 20 kph.

Frank R. Whitt and David Gordon, Bicycling Science, 2nd ed. MIT Press, 1982, p. 157-158.

Energy to overcome rolling resistance

$dW/dt = C_V/\eta\ \Sigma m \cdot g[C_R + s/100 + a/g(1 + m_W/\Sigma m)]$

C_V: Speed of vehicle

η: Overall mechanical efficiency of transmission

Σm: Total mass of vehicle, rider and baggage

g: Gravitational acceleration

C_R: Coefficient of rolling resistance

s: Upslope (%)

a: vehicle acceleration

M_W: Effective rotational mass of wheels

Energy to overcome aerodynamic drag

$dW/dt = 0.5\ C_V/\eta\ C_D\ A\ \rho\ (C_V+C_W)^2$

C_V: Speed of vehicle

η: Overall mechanical efficiency of transmission

C_D: Aerodynamic drag coefficient

A: Frontal area of vehicle and rider

ρ: Air density

C_W: Headwind

DARPA Grand Challenge

- Military contractors gave limited results.
- 1st race: March 2004, 229 km; No finisher.
- 2nd race: Oct 2005 (desert dirt roads) 5 finishers.
- 3rd race: Nov 3, 2007 (in traffic): 6 finishers.

http://www.darpa.mil/grandchallenge/index.asp

Autonomous cars are coming

Cruise control and collision avoidance systems are getting more sophisticated.

Expect to see a self-driving car in 10 years.

Opportunity for a new urban transportation mode

- Ultra-light single occupancy autonomous pods.
- Pods link electronically for families and shoppers.
- Public and private pods mix.
- Operates as a rail-less Personal Rapid Transit (PRT)

Autonomous vehicles are already here

Photo shows the autonomous commuter train in Lille, France. Trains run on 2 minute headways at peak times.

- Trains to satellite terminals at airports.
- Commuter trains in Europe & Canada.
- Elevators & escalators.
- Factory automation.

Personal Rapid Transit (PRT)

Fully autonomous vehicles on a reserved guideway.

Small vehicles.

Nonstop service using most direct route.

Off-line stations.

On demand access.

Human Powered Vehicles

- An HPV has hit 130 kph on level ground with only human power.
- Streamlining is essential.
- Optimized for minimum energy consumption.

http://www.ihpva.org/Records/

Electric Bicycles

- An electric helper motor is commercially available for bicycles.
- If < 32 kph, legally a bicycle in US.
- May be treated as moped elsewhere.
- 2 wheelers are most of world's electric vehicles.
- Biggest market is China.

http://www.ebikes.ca/

http://www.bionx.ca/

http://www.evsolutions.net/

High fuel efficiency

- In 1980, Douglas Malewicki built a car weighing 105 kg empty.
- It achieved 1.49 l/100km at 89 kph using a 1900 W petrol engine.
- An early pod: small, streamlined.

http://www.canosoarus.com/03CalifCommuter/CalCom01.htm

Maximizing fuel efficiency

The UBC supermileage student team used a pod with a gasoline engine to get 0.075 l/100km at SAE supermileage event in June, 2006.

This is by no means a practical vehicle, but it indicates that 2l/100 km is not an ambitious target.

Electrathon

High school students build and race electric vehicles.

Power from 23 kg of lead-acid batteries.

Winners cover 70 km in an hour.

No new vehicle technology is needed

Today's electric motors and batteries can produce 0.25 l / 100 km.

Set pod empty weight to 50 kg.

Set pod maximum speed to 50 kph.

Streamline with frontal area of 1 m^2.

City travel does not need long range.

Battery can be < 8 kg.

Refuel by battery swap.

The needed technology is systems and software.

The Cogηeta solution

- Build a people-mover based on 1-person pods.
- Provide a fleet of public pods.
- Private pods use manual control on streets.
- Repurpose freeway lanes for autonomous pods and prevent entry of ordinary vehicles.
- All pods are under computer control when on dedicated paths.
- There are control gates at each entry / exit ramp.

Control system

Pods on guideway never slow and always travel at design speed.

Up to 100 pods travel bumper-to-bumper in a platoon.

Entering vehicles are launched at the precise time to join the rear of a platoon.

Pods may exit from any platoon position.

Pods are tightly controlled

Any pod seeking to enter the guideway needs to pass an electronic check.

Computer precisely times pod merge.

If vehicle cannot execute the merge, it is sent to an escape ramp and its credentials revoked.

On guideway, rider cannot control the pod.

At gates, private pods transition from manual to autonomous control.

High capacity

- Estimated single lane capacity is 11,500 people / hour.
- Exceeds the 2,300 for a freeway car lane.
- It is less than the 15,000 for bus rapid transit and the 50,000 of a subway.
- 2 to 6 pod lanes would fit in the space required for a lane of cars or a train track.

This is based on the assumption that vehicles are 3m long and travel bumper-to-bumper at 40 kph. We assume that at maximum capacity, there is one platoon every 30 seconds with a 4 second gap between platoons.

Erico Guizzo, "How to Keep 18 Million People Moving", Spectrum, June 2007.

Are the pods safe?

With no driver control, would expect similar safety to autonomous trains.

Autonomous commuter trains have operated in Lille, France since 1983 and Vancouver, Canada since 1986.

Estimated Lille motor vehicle accident rate per person is 29x autonomous rate.

US motor vehicle accident rate per km is 20x global autonomous rate. (42x for fatal).

Capital costs

An abandoned rail line near Seattle is being acquired by local government.

A consultant estimated costs per km and per station.

Paths and stations for a 20 km line would cost:

Commuter rail: $198M to $371M

Autonomous pods: $39M to $97M.

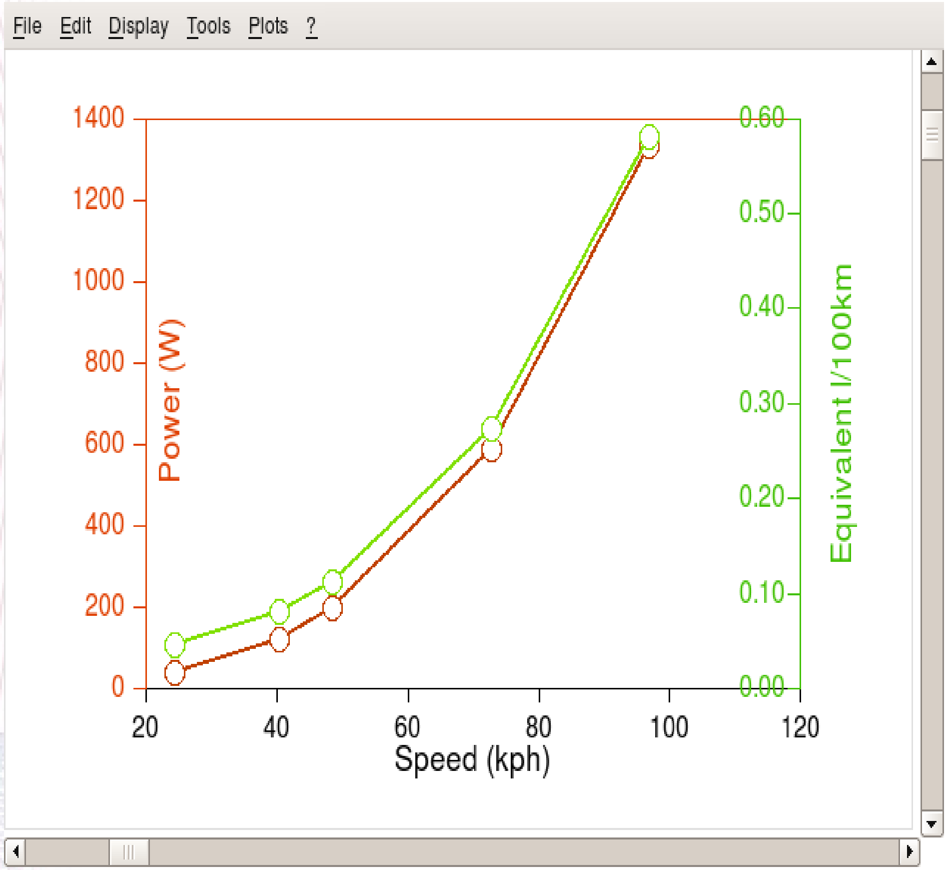
- Does not include cost of replacing 6 grade crossings.

By contrast, an 8 km Seattle light rail project is budgeted at $1.9B.

50 kph not fast enough?

- A commuter train that hits 80-100 kph peak speeds only averages 40 kph when you count stops.
- Commuter rail is slower than this when you include passenger wait times.
- In congested traffic, cars may average only 15-25 kph.
- With no stops, a low speed vehicle is faster than a high speed one with stops or congestion.

Can it go faster?



- Yes, but fuel consumption goes up.
- A city can set the speed that attracts riders.

The Elcano Project

Build a pod demonstrating low cost autonomy.

Build more vehicles.

Build a control system that demonstrates the personal people mover.

Make it all open source.

Hardware components

Recumbent tricycle

Hub motor

Li battery

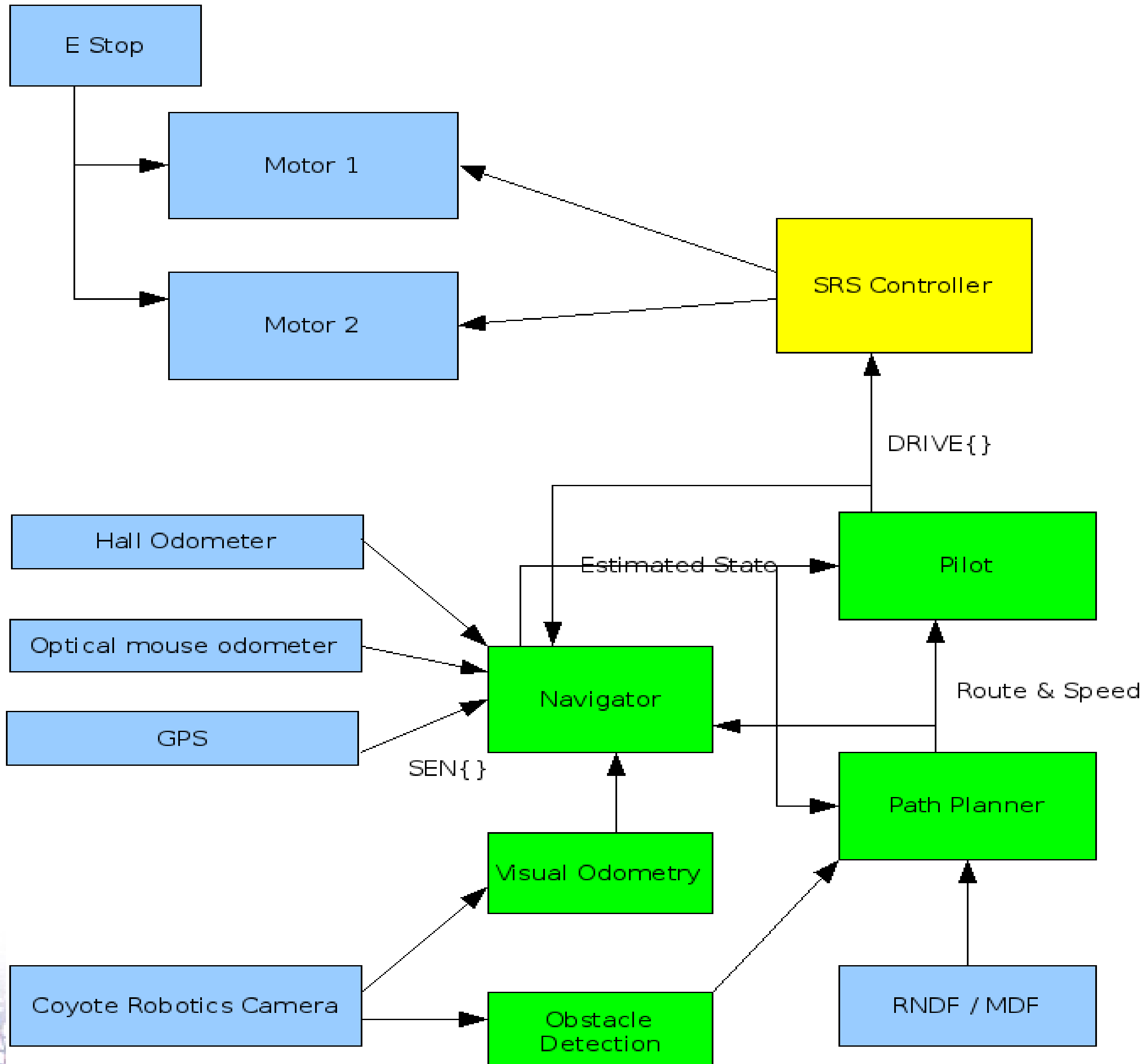
Motor & brake controller

Steering actuator

Camera

Microcontrollers

Software Architecture



Software Components

Motor controller: Execute “DRIVE” commands.

Pilot: Generate commands to follow a cubic arc at a set speed profile.

Navigator: Find current location and heading.

Camera monitor: Pick lane following, visual odometry and obstacle avoidance from smart camera.

Path planner: Generate arcs and speeds for requested trip.

Emphasis on Software

Vehicle specific behavior belongs to the motor/steering controller.

Gamebot interface:

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DRIVE {Speed ComandedSpinSpeed}
{FrontSteer ComandedSteerAngle}
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Open source simulator: USARSIM

Localization from digital maps (RNDF), lane following and odometry.

Main AI is vehicle independent.

Autonomy is 1st step

Any vehicle can use the software.

Making an autonomous vehicle is a 6 month project.

Real technical challenge is to safely control several vehicles.

Marketing the system is a major challenge.

Getting Involved

http://sourceforge.net/projects/urbanchallenge/

tyler@tfolsom.com

Engineers

Software developers

Artists and graphic designers

Business people

Letters of support from potential customers and partners