Swarm Robotics

Communication and Cooperation over the Internet

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UCLA Applied Mathematics REU 2011

Swarming

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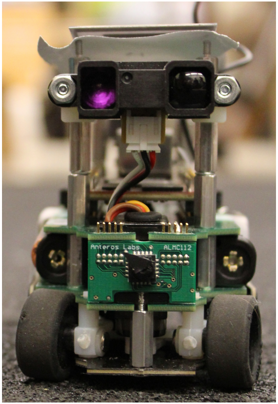
Definition:

Collective behavior of decentralized, self organized systems

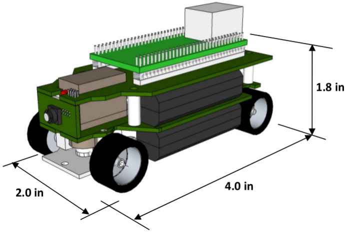
Third Generation Micro-Cars

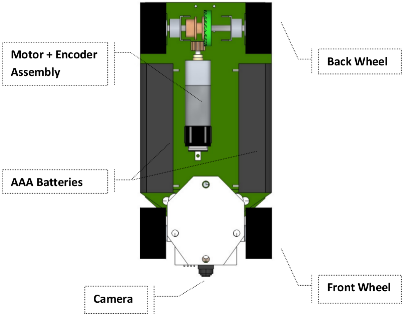


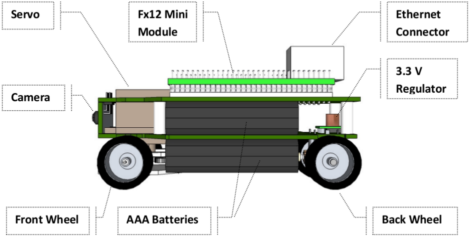
- Short or long range IR sensor to detect barriers
- 350 MHz FPGA for on-board processing (Upper Board)
- 50 MHz ARM microcontroller for velocity and steering control (Lower Board)
- Two radios for communication

- Program in C using Xilinx Studio
- Communication between upper and lower boards
  - No shared memory and limited streaming variables

Third Generation Micro-Cars







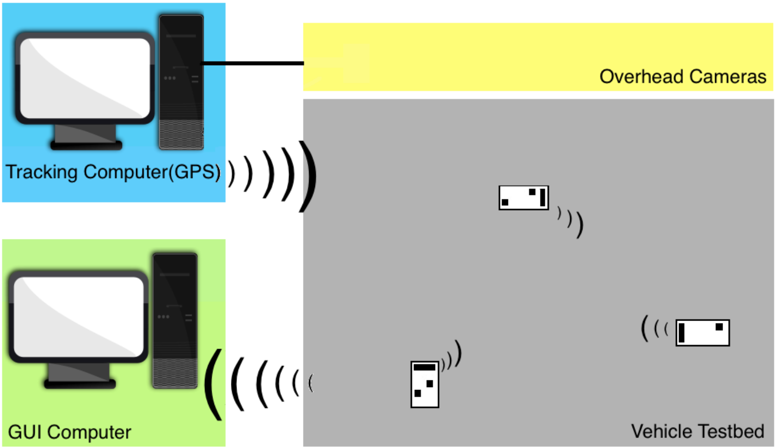
Lower Board:

- Transmit position (GPS)
- Steering control

Upper Board:

- Intervehicle communication
- GUI
- Processing

Testbed Communication Setup



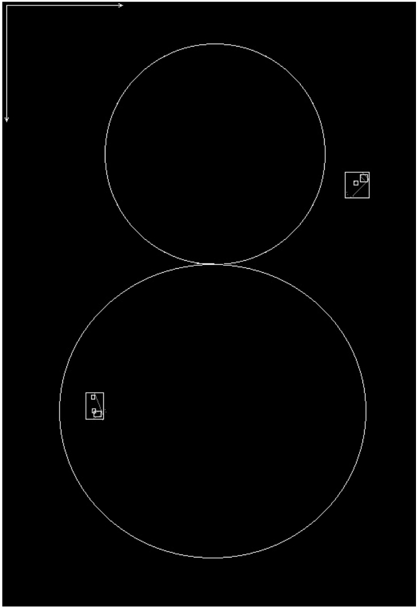
Lower board radio:

Tracking computer sends locations to individual cars

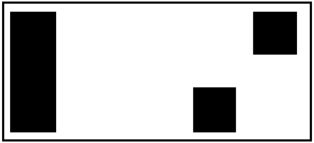
Upper board radio:

Intervehicle communication and GUI interface

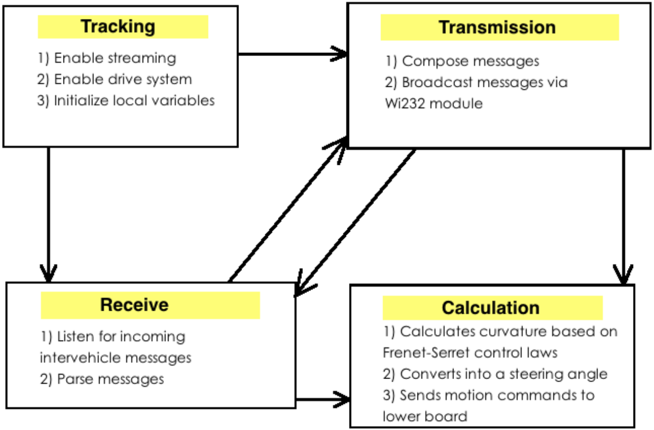
Tracking System (GPS)



- Binary tags identify cars
- Thresholding
- Contour mapping



Peer to Peer 2010



- Finite state machine with token based broadcasting
- Daisy Chain algorithm and coupling

Peer to Peer 2010

Problems:

- Encountered lossy transmission problems
  - Enters infinite receiving loop if header byte is lost
- Internal clocks not synchronized
  - Resulted in interference between transmitted messages
- Used overhead camera tracking broadcasts to locate peers
  - Limited streaming between lower and upper boards

Peer to Peer 2011

Objective:

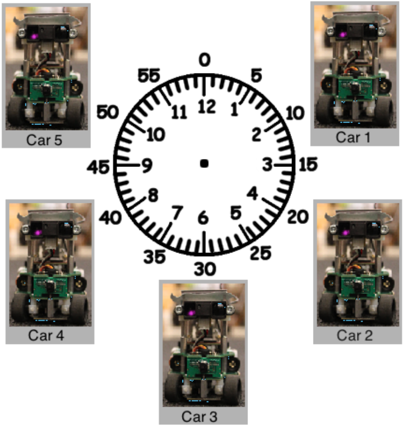
- Set up a peer to peer network protocol for sharing information
- Enable swarming algorithms to share data about the environment and cooperatively execute tasks

- Rapidly updated information will compensate for lost messages

Peer to Peer 2011

Plan

- Implement interrupt handlers for sending and receiving messages via upper board radio
- Time-scheduled broadcasting for individual cars
  - Requires clock synchronization



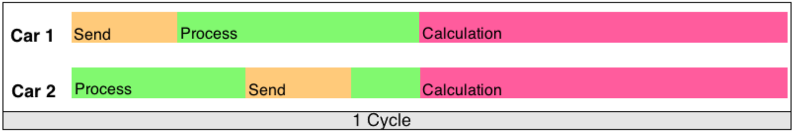
Peer to Peer 2011

Message:

	Number of Bytes
Header	1
Car ID	1
X Coordinate	2
Y Coordinate	2
Heading	2
IR Sensor Distance	2
Terminator	1
Total	**11**

Broadcast:
115200 bps $\longrightarrow$ 1.2 ms per broadcast $\longrightarrow$ 10.8 ms for 9 cars
GPS and Lower Board Streaming:
30 Hz $\longrightarrow$ takes 33.4 ms to update

Peer to Peer 2011



Processing:

Leave 1 ms after each send to parse and store the message

Calculation:

Remaining time reserved for onboard calculations and commands to the lower board

Peer to Peer 2011

Objectives

Tasks

- Follow a prescribed path
- Dynamically avoid obstacles
- Target search
- Swarming/Multi-robot Algorithm

- Robots have no apriori knowledge of map
- Know the position of other robots updated through peer to peer communications

Path Planning Algorithm

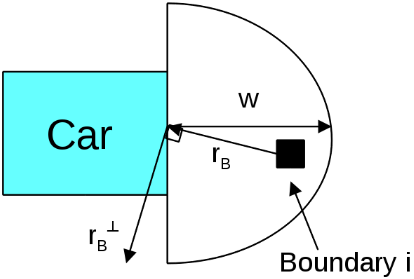
Potential Field

- Target emits attractive force.
- Boundary and peers emit a repulsive force.
- Car moves in the direction of the sum of all forces.

$$F = Q_r \left(C \frac{r_t}{\|r_t\|^2} + Q_r \sum_{i=1}^{K-1} \frac{r_i}{\|r_i\|^2} + \sum_{i=1}^{L} B_i \right)$$

Q_r: car potential (< 0)
C: target potential (> 0)
r_i: vector from i-th car to current car
r_t: vector from target to current car
K: number of cars
L: number of boundary points
B_i: i-th boundary term

The Boundary Term, B_i:



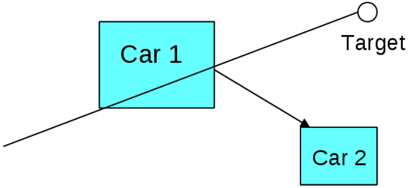
- No boundary i sensed within semicircle means $B_i = 0$
- Otherwise,

$$B_i = B_r \left(\frac{r_B^{\perp}}{\|r_B\|^2} \right)$$

where $B_r < 0$ is the barrier potential.

- Perpendicular vector direction ($r_B^{\perp}$) is arbitrarily chosen.
- Avoid scenario of all cars passing a boundary on the same side and creating a traffic jam.

To go right or left . . . that is the question



- A line drawn between the target and the car separates the testbed into two regions.
- $r_B^{\perp}$ is chosen to be a vector in the region that contains less cars.

Does it actually work?

- In simulations - Yes
- In practice -
  Fit a curve to IR sensor data to estimate distance from the boundary. If the distance is below a threshold, the car will go perpendicular to its current heading.

Swarming Algorithm

- One car leads - the rest follow
- Stay in formation without running into peers
- Also uses the concept of a potential field

Morse Potential Equations

$$\frac{dx_i}{dt} = v_i$$

$$m_i \frac{dv_i}{dt} = \left(\alpha - \beta \|v_i\|^2\right) v_i - \nabla U(x_i) + \sum_{j=1}^{N} C_0 \left(v_j - v_i\right)$$

$$U(x_i) = \frac{1}{2} C_l (x_i - y)^2 + \sum_{j=1}^{N} C_r e^{-\|x_i - x_j\|/l_r} - C_a e^{-\|x_i - x_j\|/l_a}$$

x_i	: i-th car's position	C_0	: velocity alignment coefficient
V_i	: i-th car's velocity	C_l	: leader following coefficient
y	: position of leader car	C_r	: car repulsion coefficient
N	: number of cars	C_a	: car attraction coefficient
α	: self-propulsion	l_r	: repulsion length
β	: drag	l_a	: attraction length
U	: potential function		

Networking testbeds collaboration

Serial communication with cars

- Terminal Client C++
- Terminal Synchronous Client Matlab
- Cars communicate wirelessly, so intercepting communication with the computer does not interfere

Communication over internet

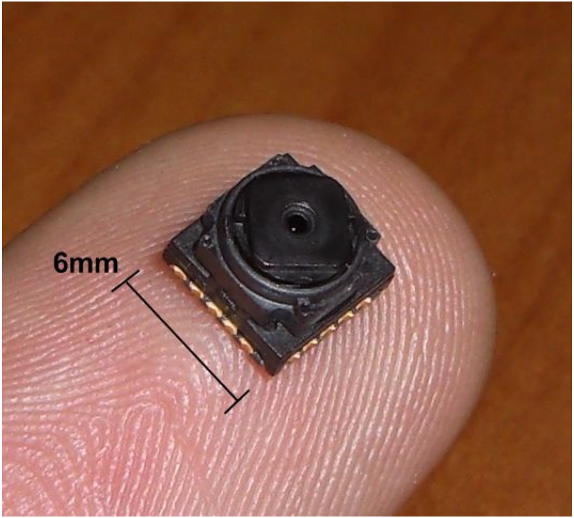
- Requires Instrumentation Control Toolbox
- Can send strings, integers, floating point numbers, even matrices of a known dimension

Collaboration

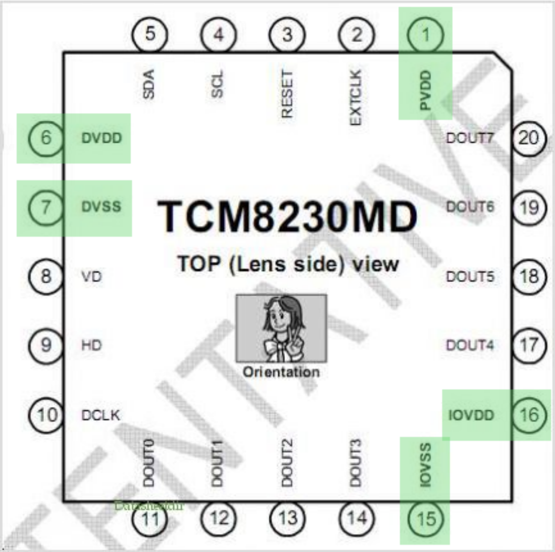
Network Communication

- Problems
  - Firewall
  - Latency to Cincinnati
  - Port overuse
- TCP/IP
- Sucessful collaboration with UC

Camera



Hardware



TCM8230MD
TOP (Lens side) view
Orientation
1 PVDD
2 EXTCLK
3 RESET
4 SCL
5 SDA
6 DVDD
7 DVSS
8 VD
9 HD
10 DCLK
11 DOUT0
12 DOUT1
13 DOUT2
14 DOUT3
15 IOVSS
16 IOVDD
17 DOUT4
18 DOUT5
19 DOUT6
20 DOUT7

Camera Configuration

- Use the built in IP to configure the 94 registers on the camera
- Registers to configure:
  - FPS
  - Resolution
  - ACF (Flicker protection)
  - ...

Summary

- Created a peer to peer network that can be combined with swarm algorithms
- Implemented both a path planning and swarming algorithm
- Collaboratively swarmed in simulation with University of Cincinnati

Future Work

- Test more algorithms
- Test with more vehicles
- Collaborate with another testbed using vehicles
- Optimize interrupts so the onboard camera can function without conflicting with peer to peer

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References

Y.R. Huang. ”Anteros Labs Micro-Car User Manual,” Private Distribution, 2010.

M. Gonzalez, X. Huang, D.S. Martinez, C.H. Hsieh, Y.R. Huang. ”A Third Generation Micro-Vehicle Testbed for Cooperative Control and Sensing Strategies,” International Conference on Informatics in Control, Automation and Robotics (ICINCO), 2011.

A. Turan, S. Bogosyan, M. Gokasan. ”Development of a Client-Server Communication Method for Matlab/ Simulink Based Remote Robotics Experiments,” 2006 IEEE International Symposium on Industrial Electronics.

W. Liu, Y.E. Taima, M.B. Short and A.L. Bertozzi, Multi-scale Collaborative Searching and Swarming, in the Proceedings of the 7th International Conference on Informatics in Control, Automation, and Robotics (ICINCO), Madeira, Portugal, June 2010.

B.Q. Nguyen, Y.L. Chuang, D. Tung, C. Hsieh, Z. Jin, L. Shi, D. Marthaler, A. Bertozzi, and R.M. Murray. ”Virtual Attractive-Repulsive Potentials for Cooperative Control of Second Order Dynamic Vehicles on the Caltech MVWT.” American Control Conference, 2005, pp. 1084-1089.

Questions?