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ADAC

iSpace

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Overview of iSpace @ NCSU

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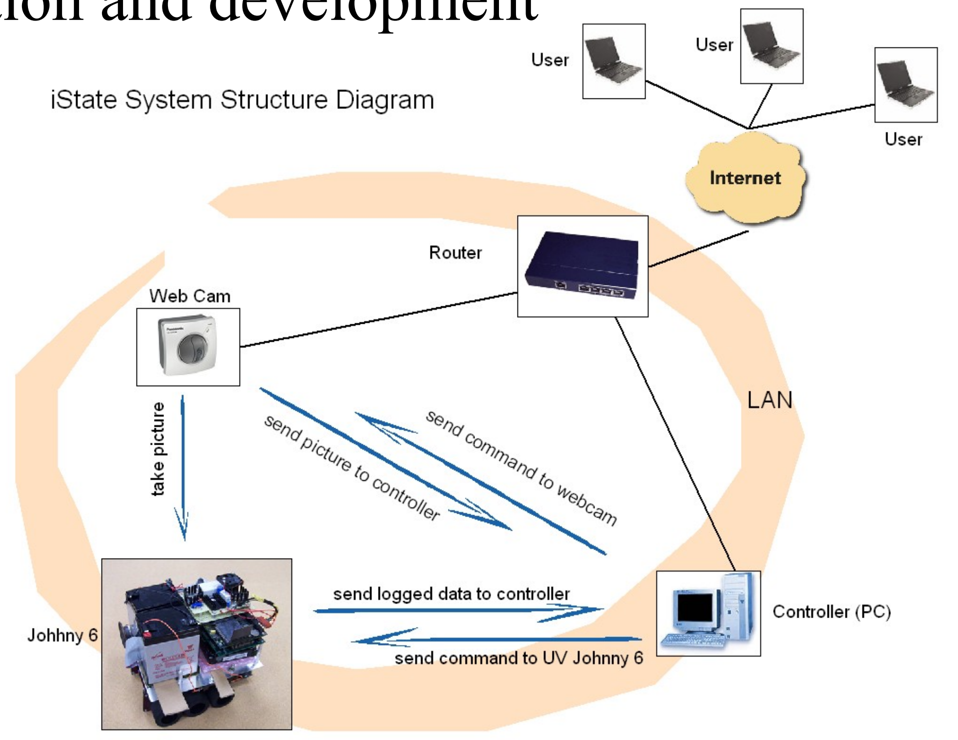
- Introduction to Intelligent Space (iSpace)
- iSpace @ NCSU realization and development
  - Flow diagram
  - iSpace settings
  - Software
  - Hardware
  - Communication network
  - Graphic User Interface



- Current research projects related to iSpace

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Intelligent Space

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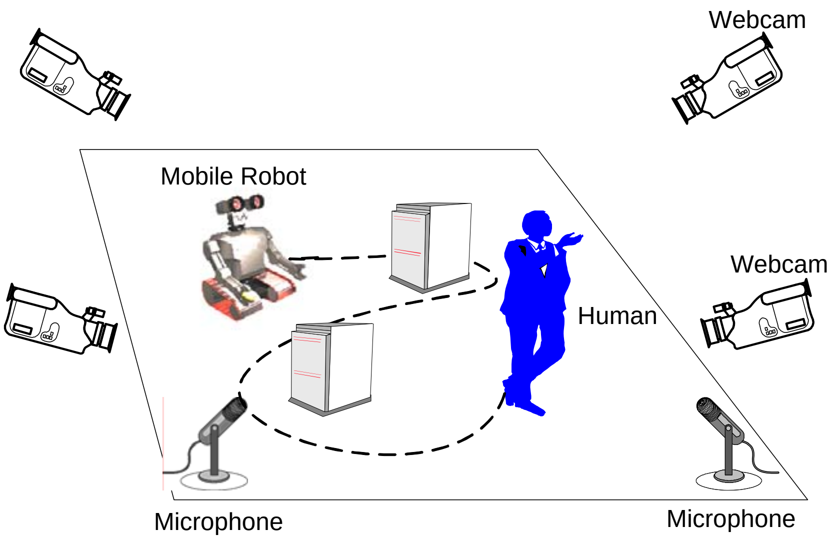


Human-machine interaction in iSpace

- A new concept to effectively use distributed sensors, actuators, robots, computing processors, and information technology over a physically and/or virtually connected space. For examples, a room, a corridor, a hospital, an office, or a planet.

- It fuses global information within the space of interest to make intelligent operation decision such as how to move a mobile robot effectively from one location to another.

Examples of iSpace

Enterprise Main Computer

Space Tele-operation
(Hubble telescope)

Futuristic Nursing Homes

Current research in iSpace

- Research topics by other universities
  - Sensor Fusion using color histogram
    - Hashimoto Lab in University of Tokyo
- Our work at NCSU
  - Real-time applications
  - Time delay effect alleviation

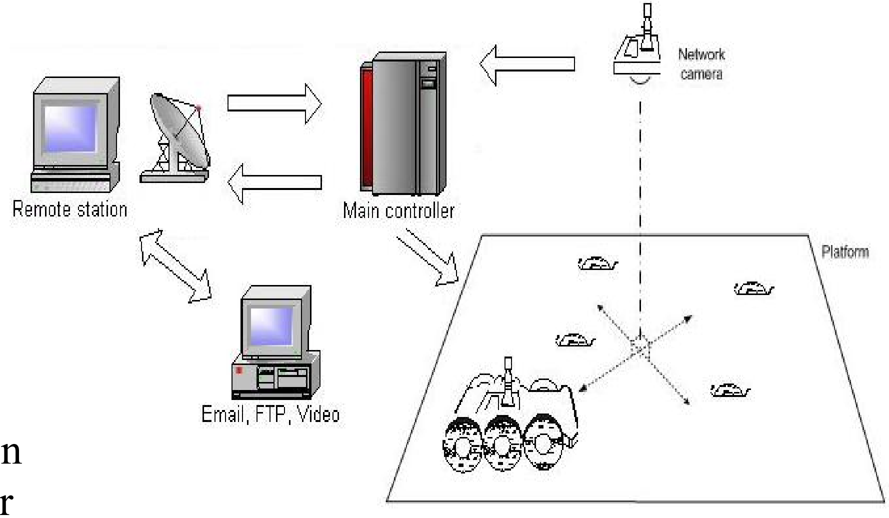
Cross-Continental Network Based Control

iSpace @ NCSU

- Objective
  - To realize and develop an iSpace infrastructure to investigate related research such as time sensitive distributed network-based control, tele-operation, and other potential applications.
- Prototyping project – Johnny6 plays fetch in iSpace
  - Demonstrate how iSpace can make superior decisions based on global information from distributed sensors (web cam) to control the actuators (Johnny 6) to complete a given task.

Structure of iSpace @ NCSU

- Software
  - Image acquisition
  - Image processing
  - Path generation
  - Path tracking controller
- Hardware
  - Sensors
    - Webcam
  - Actuators
    - Motors on Johnny6 (UGV)
  - Computer Network (IP)
    - Wired and wireless connection
    - PC 104 single board computer
    - Remote computer controller
- Graphic User Interface (GUI)



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Flow diagram

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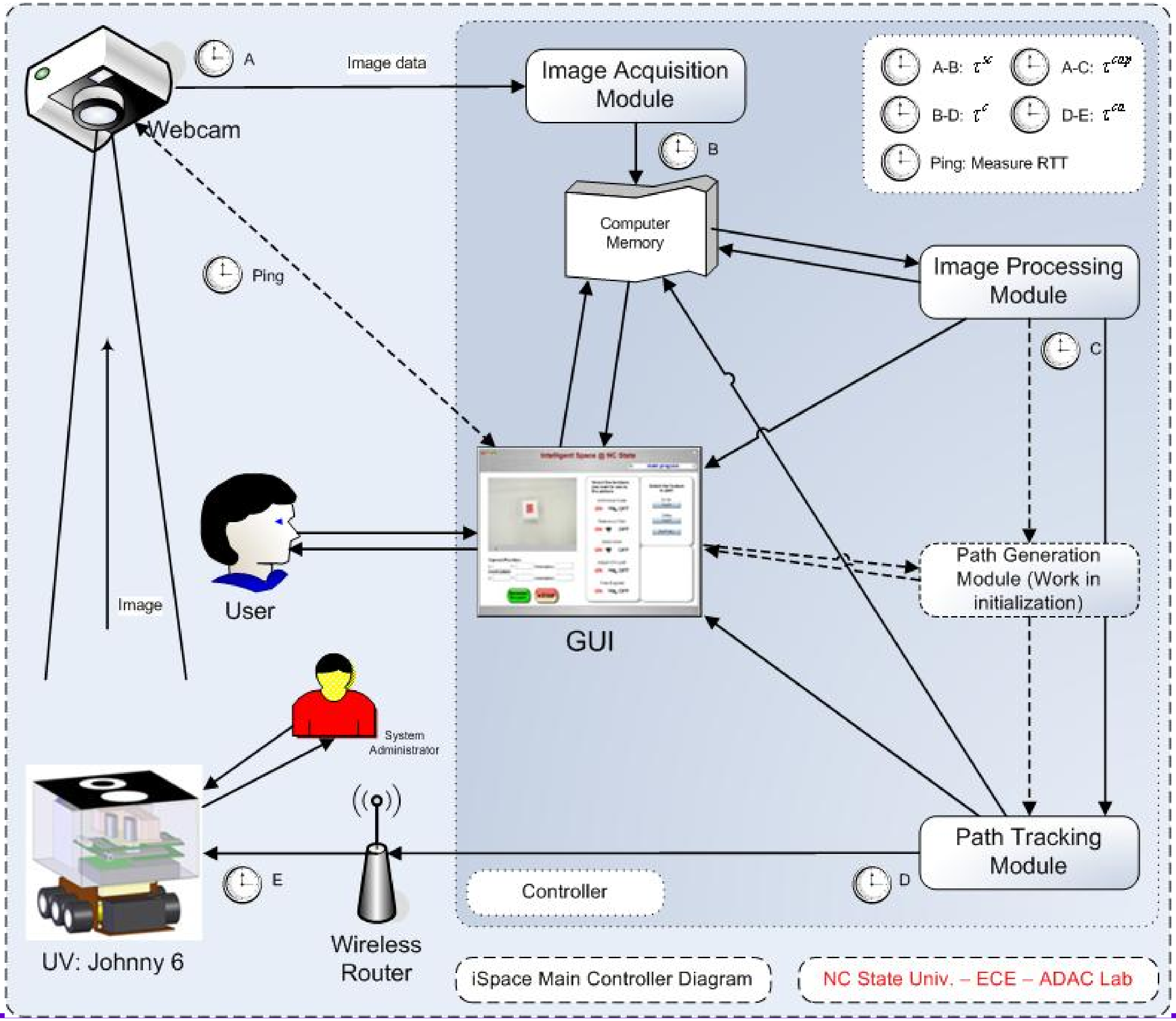


Johnny6 plays fetch in iSpace

- Game rules
  - The space with obstacles is continuously monitored by a webcam.
  - Johnny6 (an Unmanned Ground Vehicle, UGV) is to be commanded to go from its current location to a specific destination chosen by a user in a remote computing interface as quickly as possible while avoiding collisions.

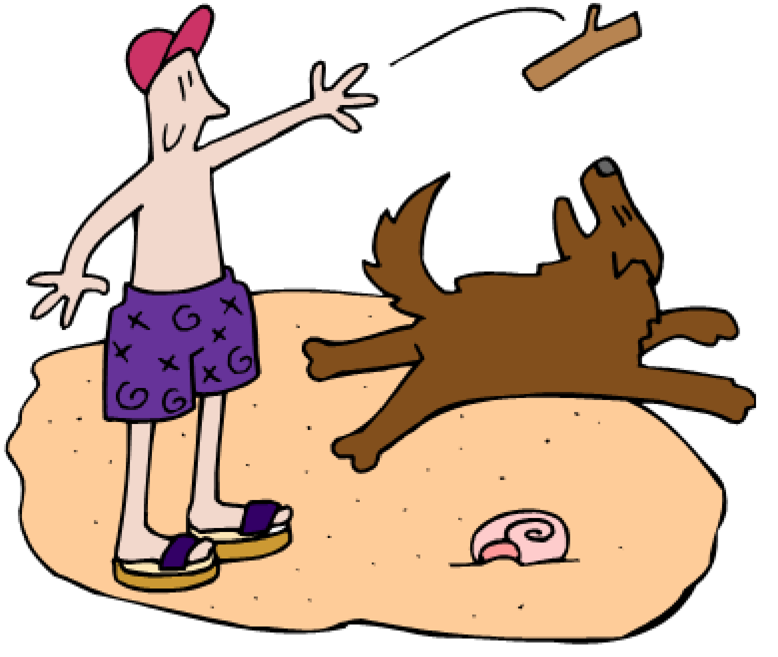


Image acquisition

- Camera setup
  - The camera is placed directly on top of the platform space, acquiring a top view from the ceiling.
  - The camera may communicate with the central controller through a wired or wireless connection.
- Image acquisition program continuously updates the image of the platform space for the image processing program.

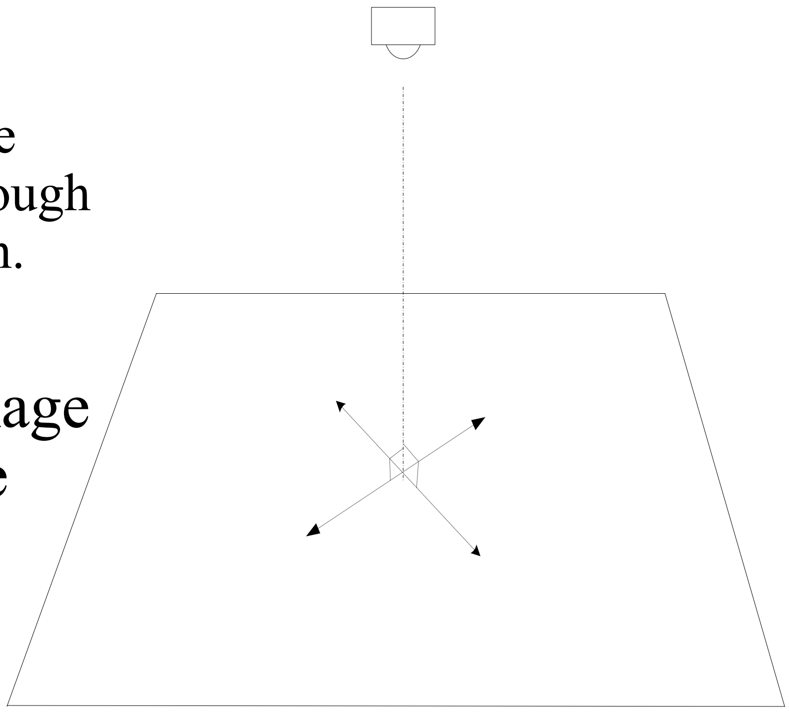
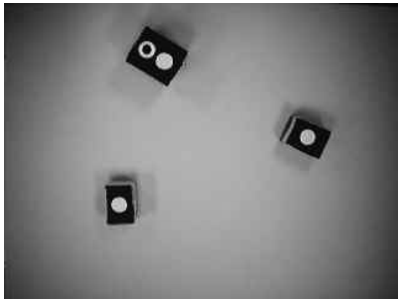


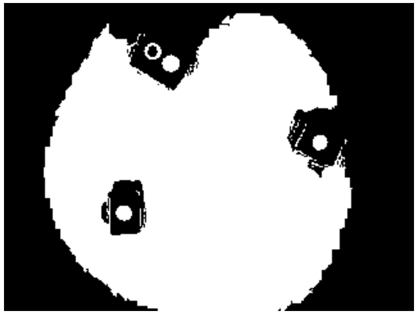
Image Processing

- Black and white conversion
  - Picture converted to black and white, with 0 and 1 indices respectively, depending on brightness of image.
- Non real-time initial scan
  - The initial position of the objects and UGV is acquired by comparing the template  with the image pixel by pixel for matches

    (takes ~ 1.2 seconds)
- Hard real-time recurrent scan
  - After the initial scan, a smaller window over the previous UGV position is used to track the UGV movement to expedite processing time.

    (takes ~0.02 seconds)



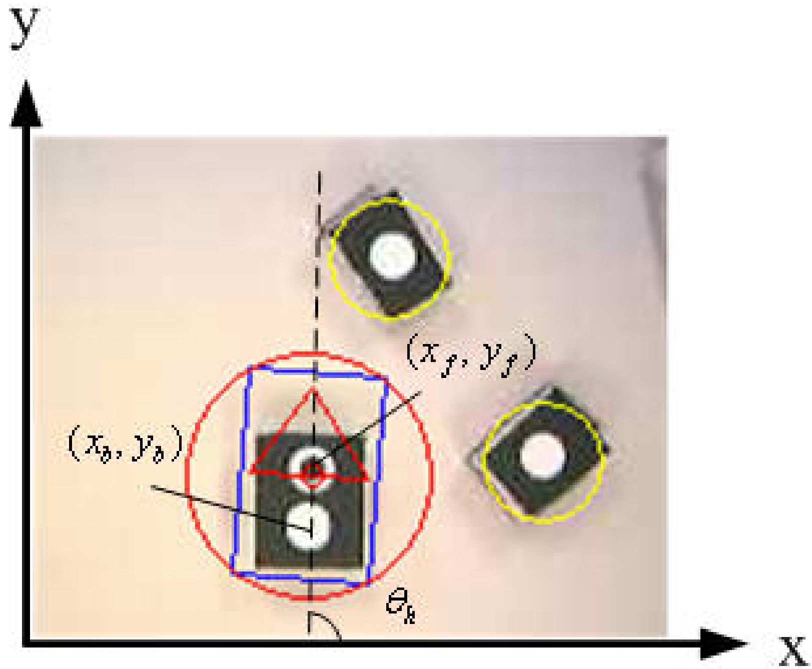


Formula for determining black / white pixels using threshold, ζ:

$$if\ \ g(x, y) \geq \zeta \rightarrow g(x, y) = 1$$
$$if\ \ g(x, y) \leq \zeta \rightarrow g(x, y) = 0$$

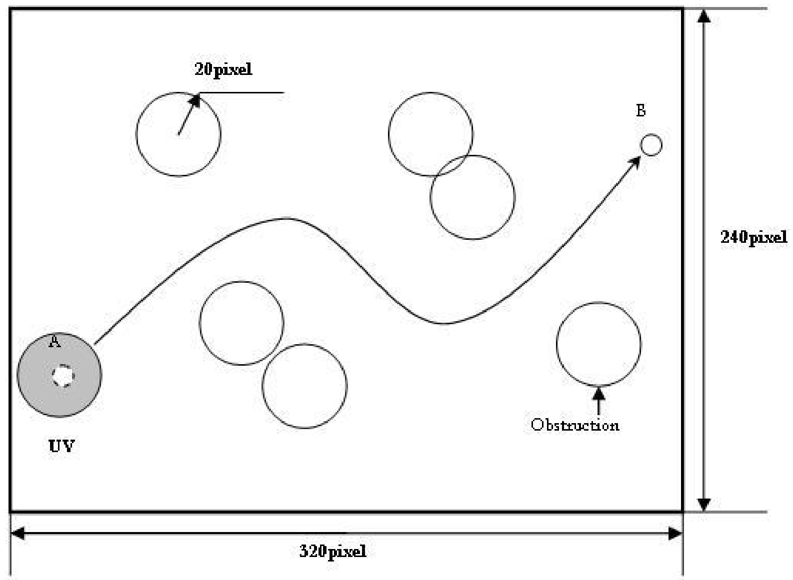
Image Processing (cont.)

- Position
  - The position that matches the template with the highest matching score (concentric circle) is declared to be the front of the UGV.
  - Positions that have the next highest matching scores (any solid white circles) are either an object or the back of the UGV.
- Orientation
  - The closest solid white circle to the concentric circle is the back of the UGV.
  - The orientation of the UGV is calculated according to the *x* and *y* positions of the two symbols that designate the front and back of the UGV.



$$\theta_h = \arctan\left(\frac{y_f - y_b}{x_f - x_b}\right)$$

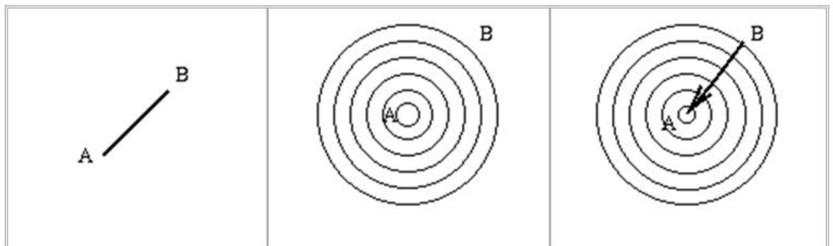
Path Generation



- Find a path from the starting point A to the end point B for the UGV
  - The path of the UGV should be as short as possible (minimize time)
  - The path of the UGV should not collide with any obstructions

Fast Marching Method

- Fast Marching Method (by J.A. Sethian, Dept. of Mathematics, UC Berkeley)
- A numerical technique that counts the shortest distance from a point to the original point with a shortest distance update algorithm
- Method Overview

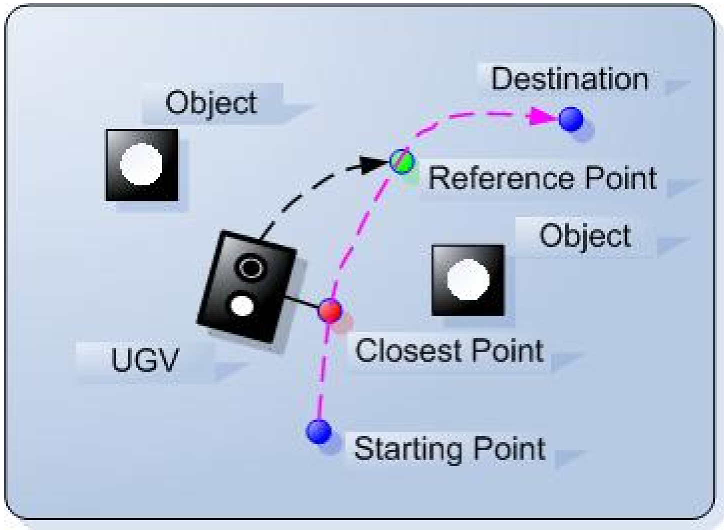


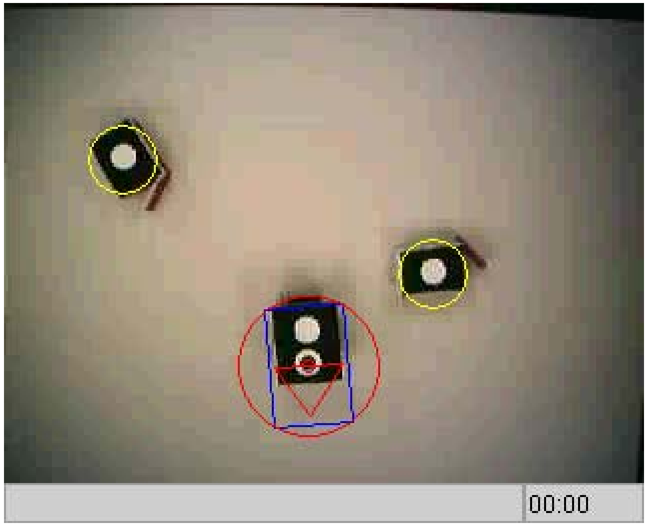
Straight line from A to B | Expanding front around A | Trace back to find path

With Obstacles | Expand front around A | Trace back to find path

Path Tracking

- The path tracking algorithm runs in every control loop and adjusts the speed and turn rate of the UGV to track the generated path.
  1. Calculate the closest point on the generated path from the current UGV position.
  2. Pick a reference point on the generated path that is a set distance in front of the UGV
  3. Calculate the speed and turn rate for the UGV to reach the reference point given its current position and orientation.





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Hardware

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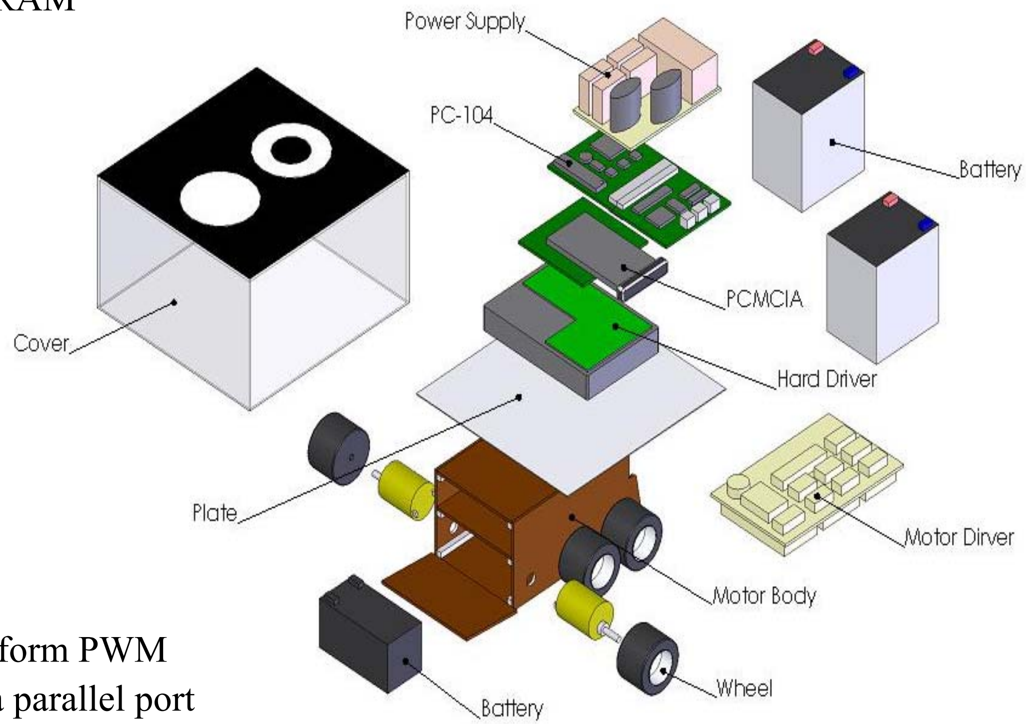
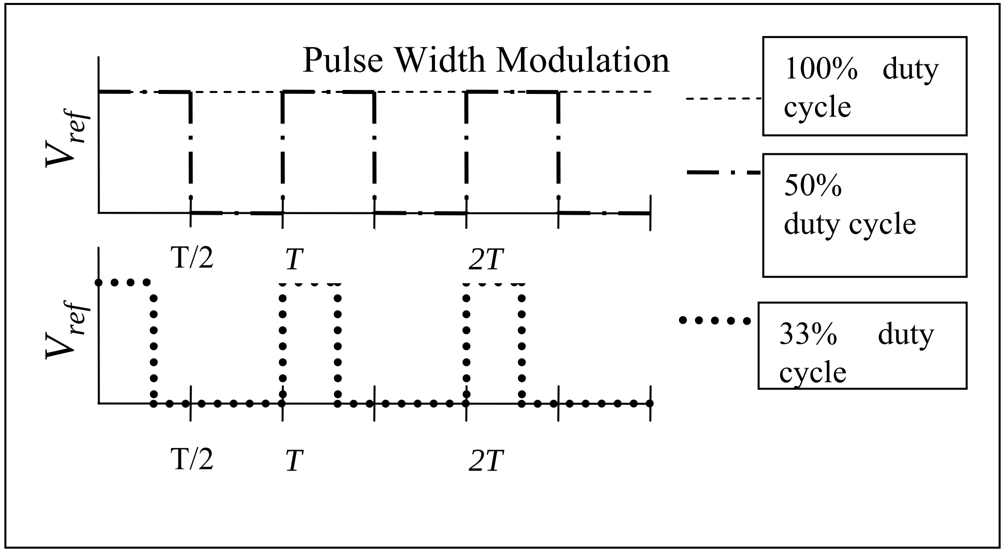
- Main Components of UGV (Johnny6)
  - PC104
    - » Pentium 266MHz, 64MB SDRAM
    - » 4MB Flash Array
    - » 10GB External Hard-drive
    - » 802.11b wireless module
    - » 5V DC
  - Motor
    - » 9V DC
    - » Rated Torque=600g-cm
    - » 165mA no load current
    - » 415mA at 600g-cm load
    - » Insulation R: 10M Ohm
  - Interface Board
    - » 5V DC
    - » Uses latches and logics to perform PWM
    - » Communicate with PC104 via parallel port
  - Power Supply
    - » 3 batteries
    - » 3 voltage regulation circuits (5V,5V, 9V)



Johnny6

Power Management

- PWM
  - Using digital signals from the parallel port of the PC104, duty cycle of the PWM is determined. This signal is then sent to the H-bridge to control the motors.
  - Based on the duty cycle, the motor sees a corresponding voltage.
    - If the duty cycle is 100%, the motor sees the entire supply voltage.
    - If the duty cycle is 0%, the motor sees no voltage.
    - If the duty cycle is 50%, the motor sees half the supply voltage, and so on.



- Power Supply
  - To ensure stability, isolation of the power supplies between the motor and the pc104 is desired.
  - Power for the UGV comes from 3 different 12V /400mAhrs batteries.
  - A separate voltage regulator is designed for each batteries to supply 5V to the interface board, 9V to the motor, 12V to the harddrive, and 5V to the pc104.

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UGV communication interface

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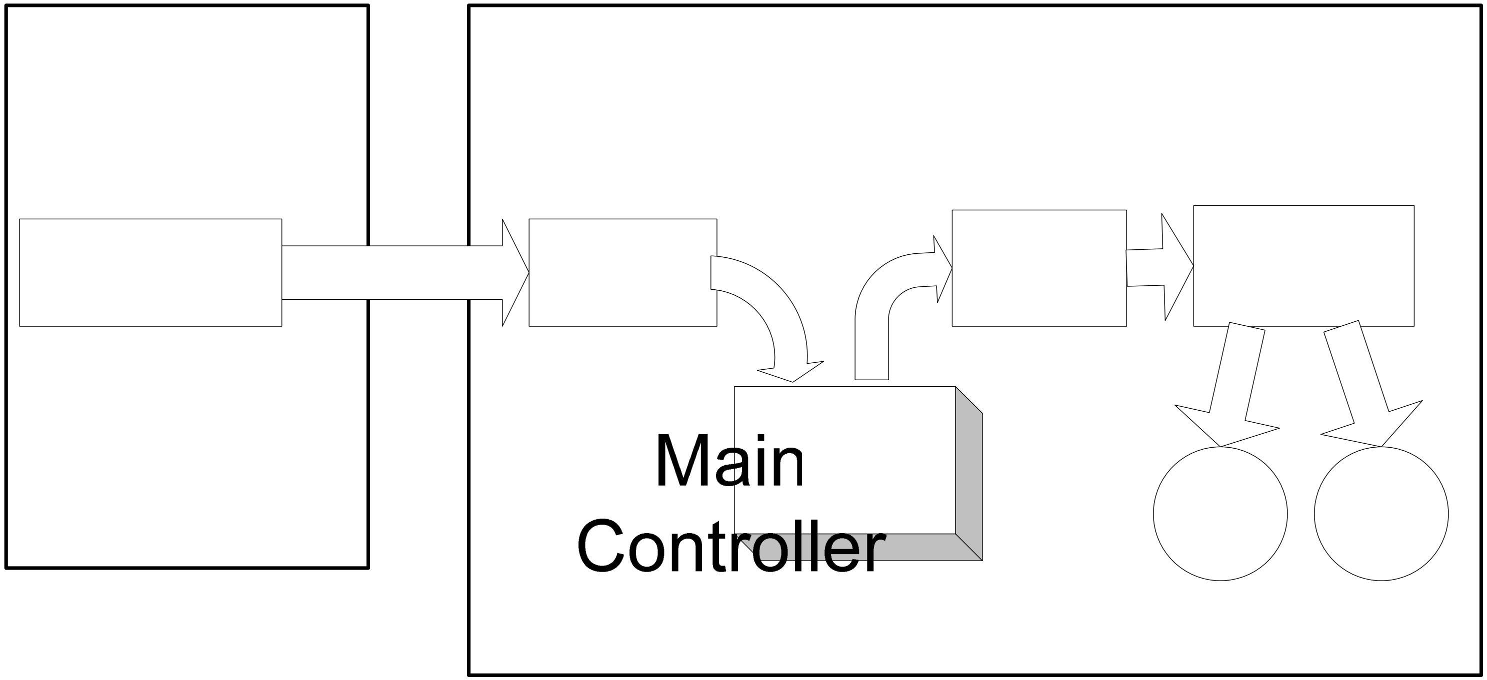

- UGV receives speed and turn rate information from control software via 802.11b wireless network channel.
- Speed and turn rate are recorded in a data file (points.txt) on the UGV.
- Data are retrieved by a driver program that controls the voltage levels of the motors.
- As the UGV moves, a new image is captured by the webcam to perform the next calculation of speed and turn rate using the software.

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Main Controller GUI

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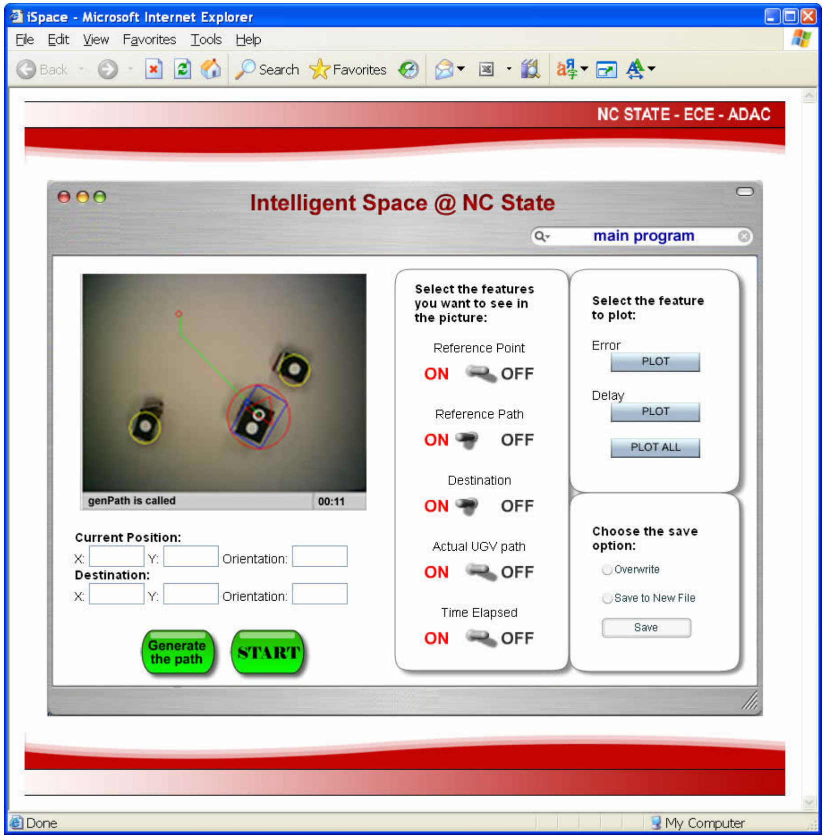
- Remote user interface
  - Display window
  - Status display
  - Action buttons
  - Display options
  - Plot selections
  - Data saving options



Infrastructure for Research

- Capabilities:
  - Hard real-time data collection
    - Image acquisition time
    - Image processing time
    - Network delay between remote user interface and the UGV.
  - Fast prototyping
    - Network-based control
    - Gain Scheduler Middleware (GSM)

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Image acquisition time

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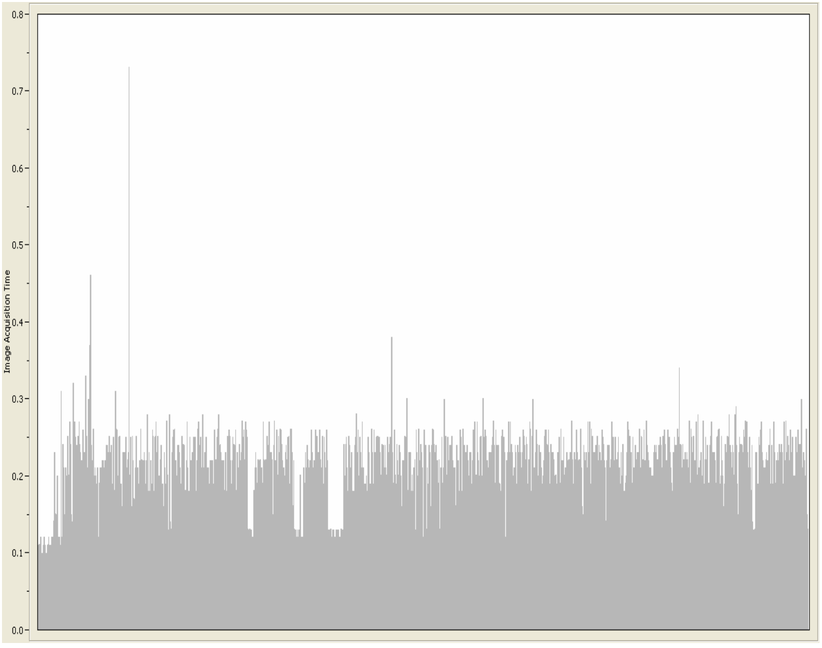
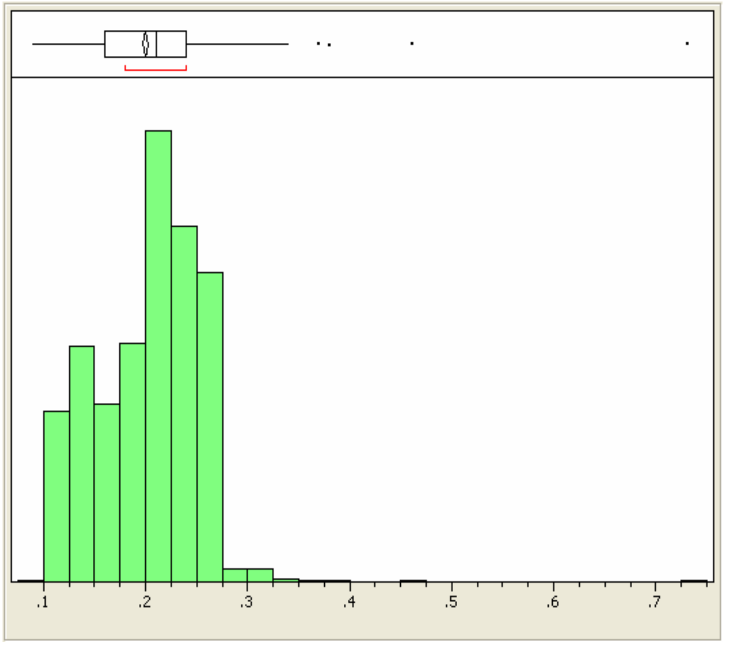
- Time for a webcam picture to be captured and saved in the harddisk
- The average time for image acquisition ~ 0.2 seconds



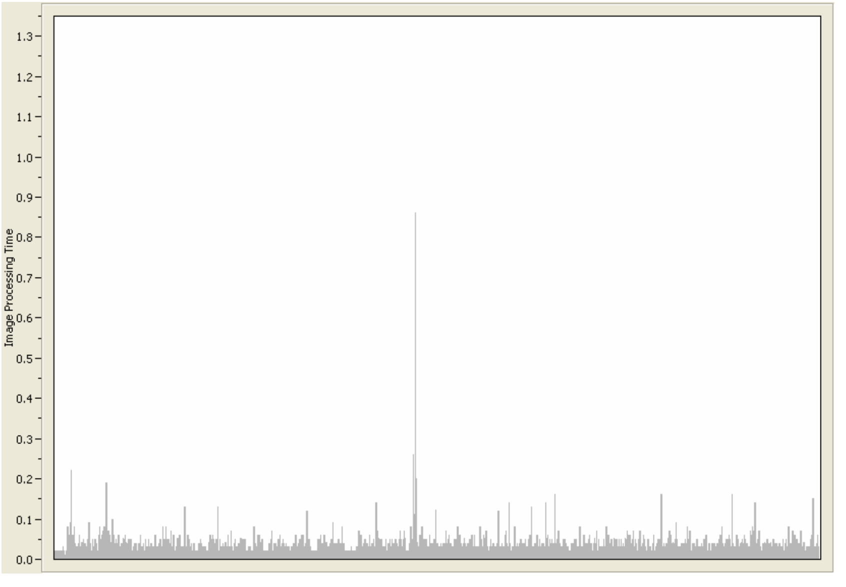
Actual image acquisition time



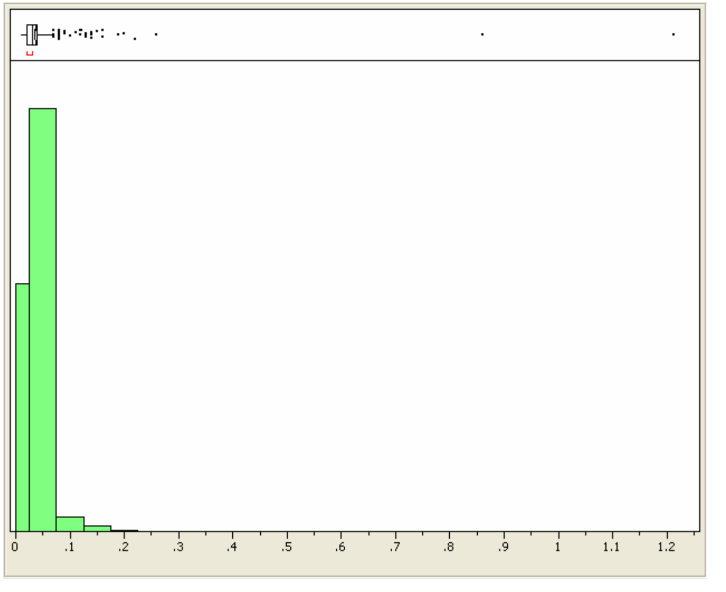
Histogram of image acquisition time

Image processing time

- Time required to extract position and orientation information of the objects and UGV from the image acquired previously
- Non real-time processing takes ~1.2 seconds (initial)
- Hard real-time processing takes ~0.02 seconds (remaining)



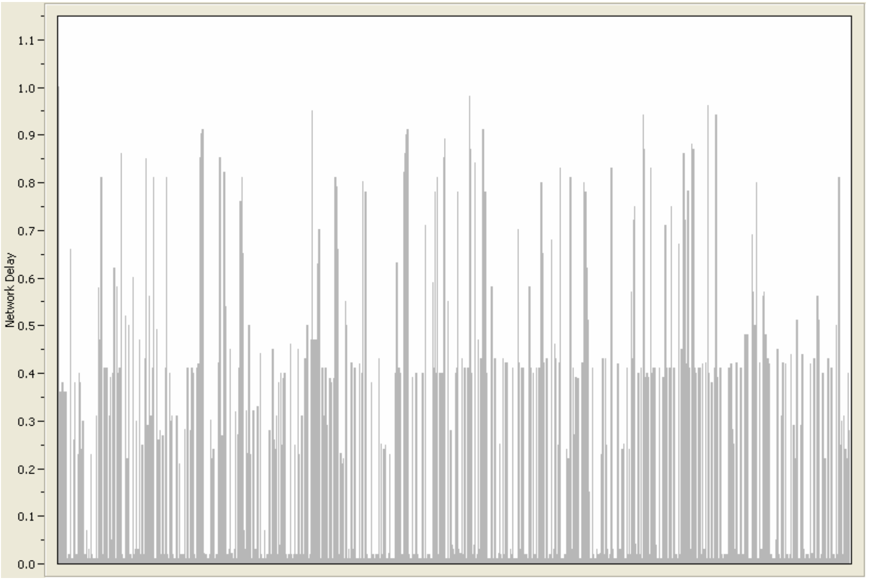
Actual image processing time



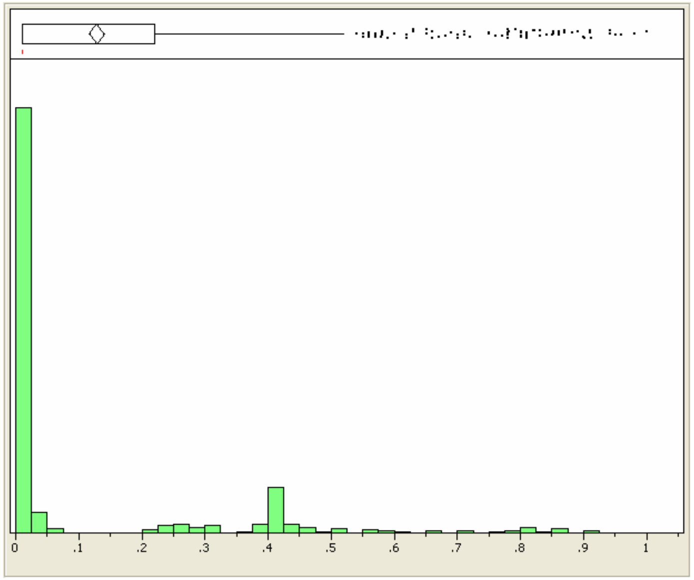
Histogram of image processing time

Network Delay

- Round-trip time between the remote user interface and the UGV over a wireless link
- The network delay is skewed to the right and has a long-tail, so the mean value of the delay is bigger than the median. (The mean is 0.129 second, the median is 0.01 second)



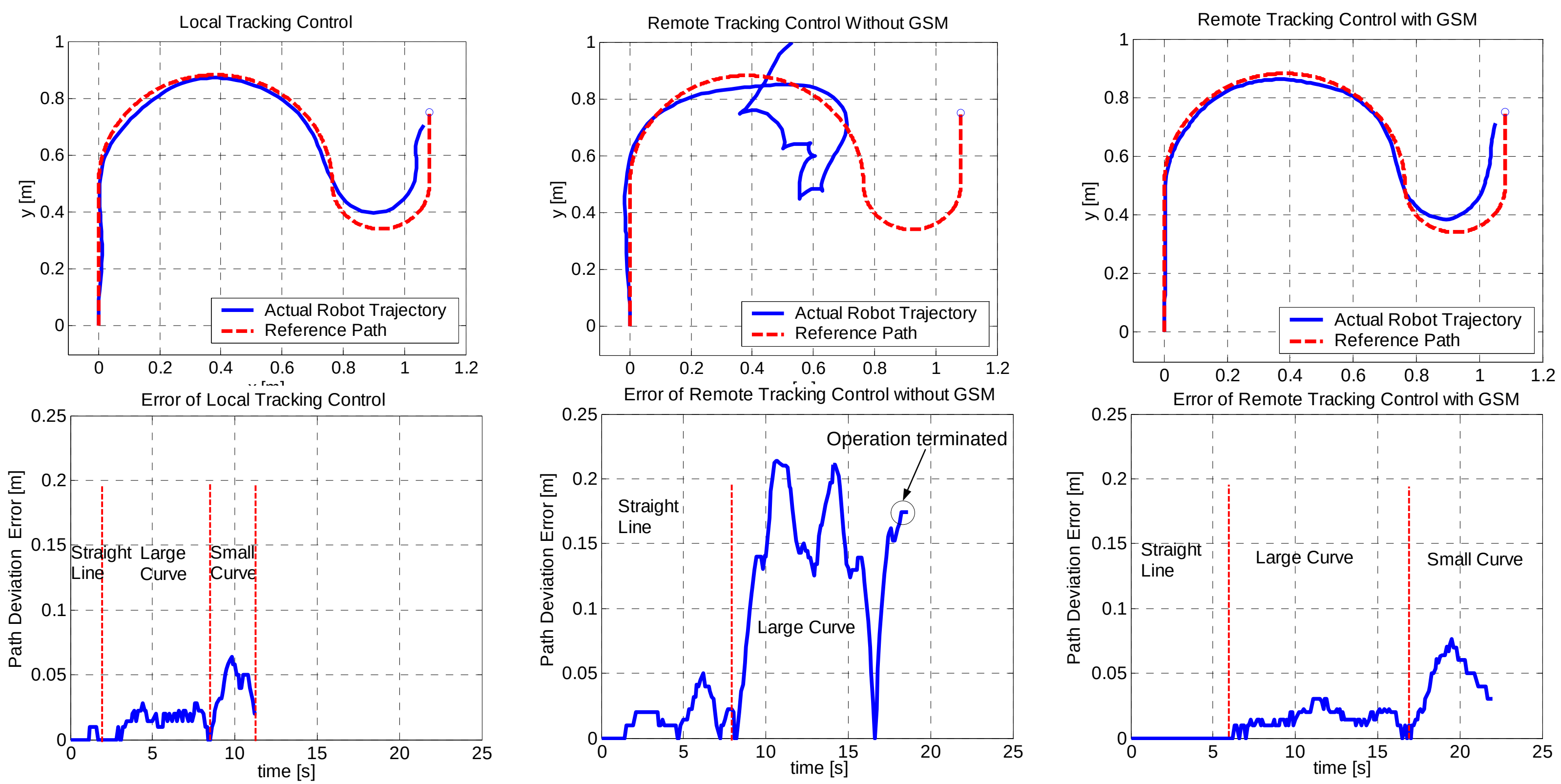
Actual network delay



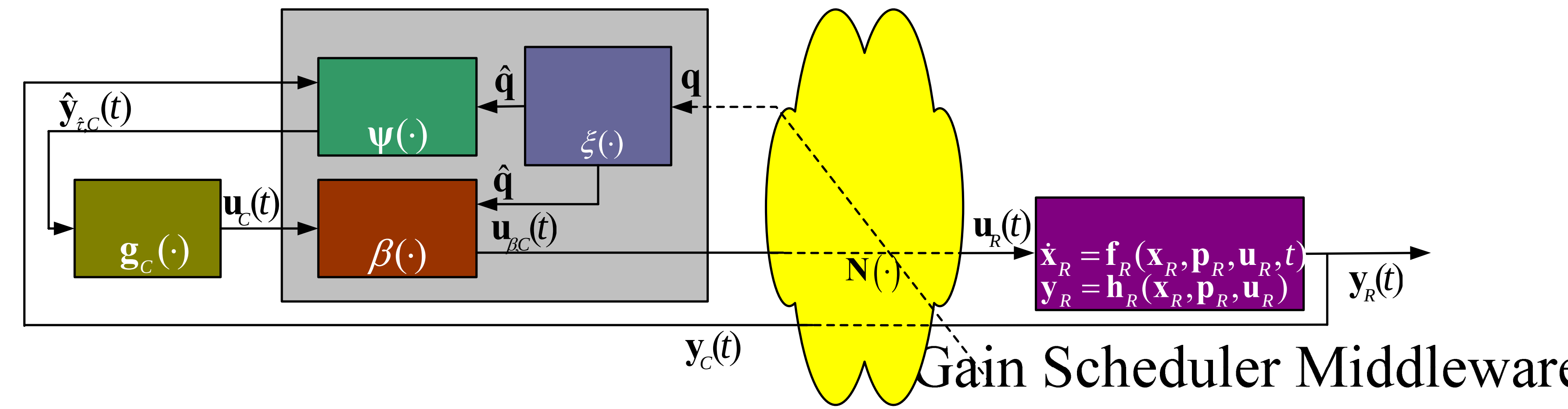
Histogram of network delay

Research Challenges in iSpace

- Research challenges in iSpace
  - » Time delay alleviation
  - » path tracking control algorithms
  - » Remote wireless control via internet

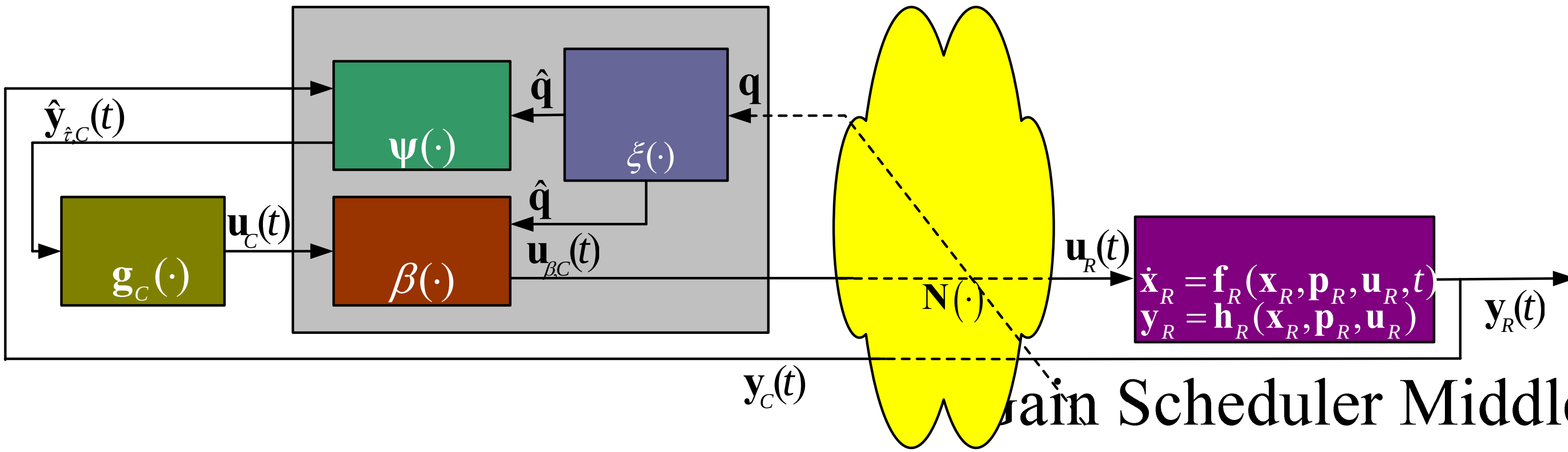


Network-based control



- Network delay is a critical issue in network-based control, as shown in the results of the iSpace project
- Gain Scheduler Middleware (GSM) is a technology that allows the communication network to be transparent to controller and remote system, alleviating the adverse effects of network delay
- GSM enables a conventional controller for network-based control purpose

Gain Scheduler Middleware (GSM)



- Gain Scheduler (GS)
  - Modify the controller output using gain scheduling to provide an optimal performance based on the current network traffic conditions
- Feedback Preprocessor (FP)
  - Pre-process the measured data before forwarding the signal to the controller
- Network Traffic Estimator (NTE)
  - Estimate the current network traffic conditions such as round-trip-time and loss rate

Conclusion

- Introduction to Intelligent Space (iSpace)
- iSpace @ NCSU realization and development
  - iSpace structure
  - Software
    - Image acquisition and processing
    - Path generation and tracking
  - Hardware
  - Communication network
  - Main Controller GUI
- Infrastructure for research
  - Hard real time data collection
  - Network based control system
- Experimental results
- Future research

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Publications and References

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ADAC Members


Thank You