TMO Turtle
with
a 90-mile Long Joystick

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Outline

• Project Configuration
• Challenges & Enabling Technologies
  – OptIPuter Network
  – Global Time-based Coordination of Distributed Actions (TCoDA)
  – Time-triggered Method-triggered Object (TMO)
• Measurement Results
• Conclusions
Project Configuration

- Webcam
- Wireless LAN
- Video stream
- Control cmd
- Joystick
- WAN
Challenges and Enabling Technologies (I)

- **Network infrastructure**
  - Low transmission latency while providing sufficient bandwidth
  - Small transmission jitter providing high quality videos and predictability for vehicle control

- **OptIPuter network** ([http://www.optiputer.net](http://www.optiputer.net))
  - High bandwidth, low latency, and low transmission jitter
  - Critical in enabling real-time wide-area distributed computing
  - The current Internet is way too short.
Project Configuration

UCSD

UCI

Joypad

Webcam

Wireless LAN

OptIPuter Network (90 miles)
Challenges and Enabling Technologies (II)

- **Software technology**
  - Timely cooperation among machines scattered over wide areas

- **GPS-based global clock synchronization**
  - Global-time-based coordination of distributed actions (TCoDA)
Essence of RT Programming: Time-Triggered Action

At time $T$ do $S$

\[
\begin{align*}
\{ & = \text{Start } S \text{ during } [T - \Delta, T + \Delta] \\
\}
\end{align*}
\]

- A fundamental & distinguishing part of real-time programming
- If $S$ is a function, a control signal for the activation of the function in a node is derived from the progression of real-time;
- Whenever the real-time clock within a node reaches a preset value $T$ specified in a scheduling table, a control signal is generated;
- In principle, $S$ may be a single assignment statement, a compound statement, or a function.
Global time and TCoDA (Time-based Coordination of Distributed Actions)

Why not let program components make Time Appointments among themselves?

Hermann Kopetz was a pioneering advocate for TCoDA
Time-Based Coordination of Distributed Actions

Imagine the Advantages of

A group of cooperating people with wrist-watches over

A group of people not using the globally referenced time

"Let’s start a chorus at 2pm"

NOT
"Open port 77 at 128.200.9.180; Wait for reply; ---"

Time-triggered Spontaneous methods
Service methods
Challenges and Enabling Technologies (III)

- **Software technology**
  - Provably reliable OS & application software technology

- **Time-triggered Message-triggered Object (TMO) technology for software engineering** ([http://dream.eng.uci.edu](http://dream.eng.uci.edu))
  - Multiple times improvement over the current practiced technology with respect to the efficiency in developing real-time application software and the reliability, analyzability, and expandability of the application software produced
High-Level RT Object: TMO

The Time-triggered Message-triggered Object (TMO) programming and specification scheme

- Meant to be a natural easy-to-use extension of the C++/Java technology into an RT distributed software component programming technology
- Supports design of distributable HRT objects and distributable non-RT objects within one general structure
- Contains only high-level intuitive and yet precise expressions of timing requirements
- Formulated from the beginning with the objective of enabling design-time guaranteeing of timely actions
Making Application Programmers' Life Easier

Structure as TMO networks relying on intelligent execution facilities

Real-Time Distributed Computing Applications

- No concerns with
  - Processes & Threads
  - Object locations
  - Low-level comm protocols

- No specification of timing reqts in indirect terms (e.g., priorities)
  - Only start-windows and completion deadlines for object methods
  - Time-windows for output actions
Measurement Results

1. End-to-end delay for video streaming

2. Transmission delay
   • Comparison between OptIPuter and the Internet
End-to-End Delay

Definition:

- The time interval from the capture moment to the play moment of a video frame.

\[ D_{e2e} = D_c + D_e + D_s + D_n + D_r + D_{dec} + D_{dis} \]
Delay Measurements

- Encoding Delay
- Sending Delay
- Receiving Delay
- Decoding Delay

Frame Size (pixel):
- 176*144: 1.47 ms
- 352*288: 14.7 ms
- 640*480: 14.7 ms
## Network Bandwidth Consumption

![Network Bandwidth Consumption Graph]

### Table: Network Bandwidth Consumption

<table>
<thead>
<tr>
<th>Resolution</th>
<th>10 FPS</th>
<th>20 FPS</th>
<th>30 FPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>176*144</td>
<td>0.4</td>
<td>0.8</td>
<td>1.2</td>
</tr>
<tr>
<td>352*288</td>
<td>1.2</td>
<td>2.4</td>
<td>3.6</td>
</tr>
<tr>
<td>640*480</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

The best quality with the camera is achieved at a resolution of 640*480 and a frame rate of 30 FPS.
Experiment Configuration

[Map showing the location of CSUF and UCI connected by a line labeled (20 miles)]
Packet Loss Rates

* Note that the packet loss rate increases exponentially as the bandwidth consumption increases. Also, its behavior is quite unpredictable.
Round Trip Delays

If the car runs at 10km/h, it moves almost 30cm in 100msec
Joystick at UCI

The era of high-precision real-time wide-area distributed computing is almost here.
Car at UCSD
Conclusions

• We have shown ...
  – Remote control of a toy vehicle over the OptIPuter network
  – High resolution, high frame rate video streaming
  – Comparison of OptIPuter and the Internet via measurement of delay, jitter, and packet loss rates

• OptIPuter is useful because ...
  – The current Internet does not provide deterministic behaviors in terms of network bandwidth and delay jitters.
  – We need a schedulable network infrastructure with high bandwidth for time-critical distributed applications.
  – The OptIPuter showed its capability of providing high bandwidth, low latency, small jitter network to distributed applications.
Conclusions (cont.)

- TMO is useful because ...
  - TMO scheme provides natural and intuitive programming model for real-time distributed application developers.
  - TMO scheme showed its capability of supporting timely cooperation among computing nodes scattered over wide areas.

- In the future, we are going to perform...
  - Multi-party remote control such as multiple operators at different locations controlling multiple cars in the same place
Questions?

Thank you.