Real-Time Ubiquitous System: A Case Study

"Combined Scheduling of Sensing and Communication for Real-Time Indoor Tracking in Assisted Living"

M.-Y. Nam
CS Dept. UIUC

M. Z. Al-Sabbagh
ECE Dept. Ohio State University
Columbus, OH

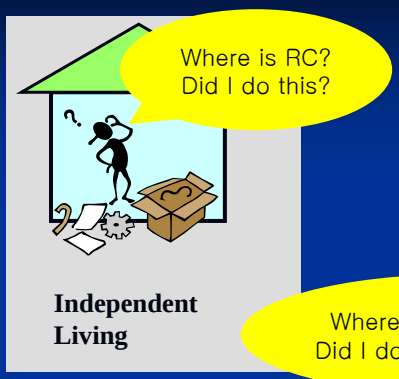
C.-G. Lee, J. Kim, M. Yoon
CS Dept. Seoul National University

Real-Time Ubiquitous System

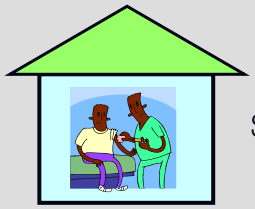
Real-Time Ubiquitous Systems

- Integrative System: Entertainment, Medical, Sensing, and Communication Devices
- Integrative Systems that provide real-time interactions with humans and environment
  - Continuous real-time monitoring of human activities
  - Providing real-time guidance
  - Real-time emergency detection and handling
  - Making our daily lives more safe and enjoyable
- How to integrate computing, wireless, and sensing devices providing such real-time interactions?

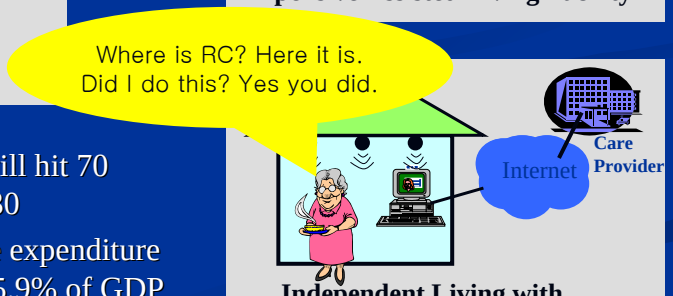
Case Study: Technology-based Assisted Living



Independent Living



Expensive Assisted Living Facility



Independent Living with Technology Assistance

- Age over 65 will hit 70 millions in 2030
- US health-care expenditure will grow to 15.9% of GDP ($2.6 trillion)

Real-Time tracking Human/Objects for Assisted Living

- Services we wish to provide:
  - Object finding
    - Where did I leave my eye-glasses?
  - Checking if actions were taken
    - Did I eat my pills today?
  - Behavior analysis
    - Early symptom of diseases

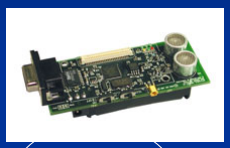
Real-Time Tracking of Human/Object can solve

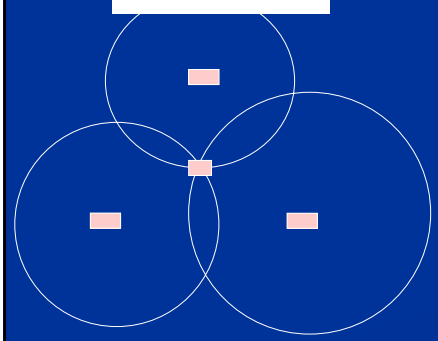
Our Sensing Infrastructure (Ultrasonic and RFID)

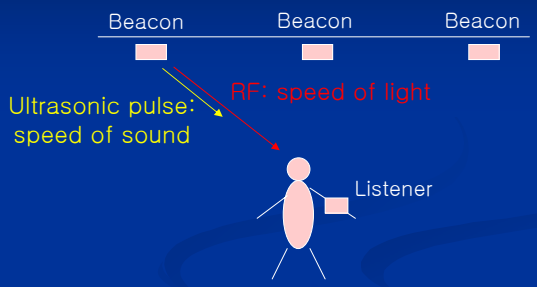
- Wristband with
  - "Ultrasonic Listener" and
  - "RFID reader"
- Tracking user: Ultrasonic Listener on a Wristband
- Tracking object carried by the user: RFID reader of the Wristband

Ultrasonic Sensing

- Crossbow Cricket







Localization accuracy: 10cm

Real-time tracking: Uses Least square and a Kalman filter with continuous sampling

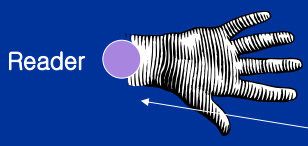
Tracking performance: Sampling frequency

RFID Based Sensing

- SkyeTek RFID Reader and RFID Tags

M1-mini RFID Reader

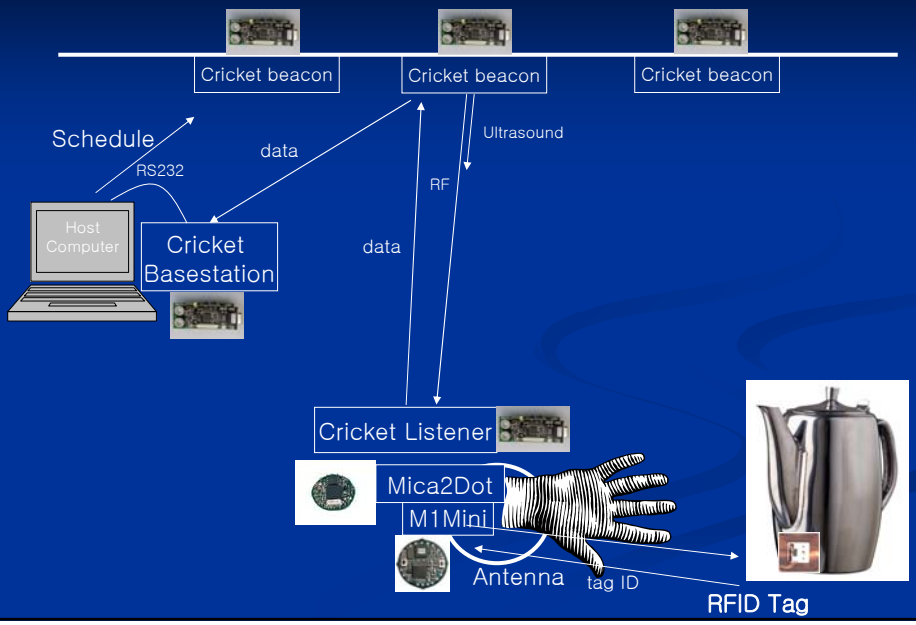
RFID Tags



Can read within 10 cm proximity

Tag

Entire System Operation

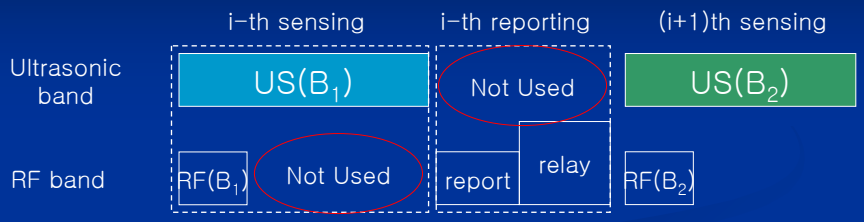


Scheduling Issue

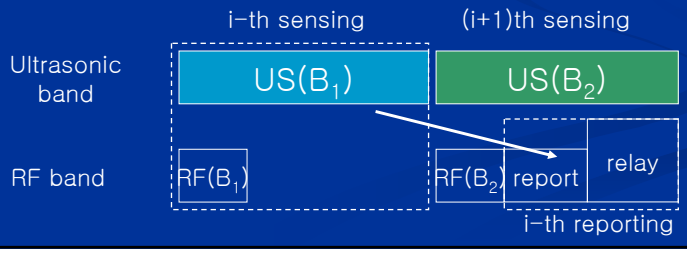
- Two types of active signals
  - Sensing: Ultrasonic signals from multiple beacons
  - Communication: Various RF messages from multiple beacons, listeners, and host computer
- Original cricket method: Carrier sensing and random arbitration
  - Maximum possible sampling rate is limited
  - Poor real-time tracking
- Our new scheduling method
  - Collision-free scheduling providing much faster sampling
    - Combined schedule of “Sensing” and “Communication”
    - Location-aware dynamic scheduling: further improvement of sampling rate
    - Mobility-conscious scheduling: energy saving

Pipelining sensing and reporting stages

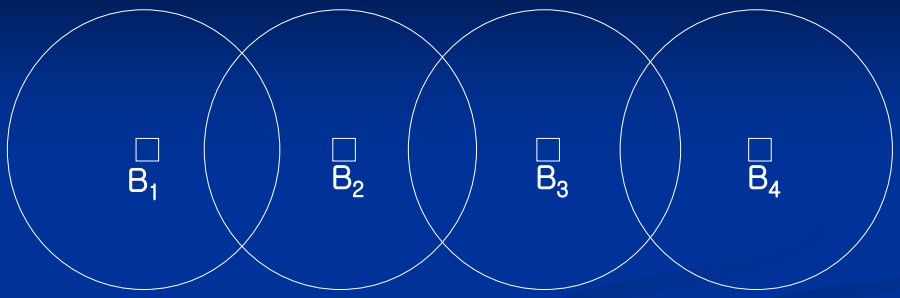
- Naïve collision-free approach: Sequential schedule



- Pipelining sensing and reporting



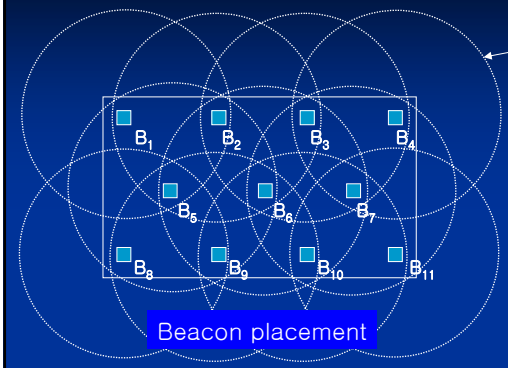
Concurrent Executions



- Simple round-robin

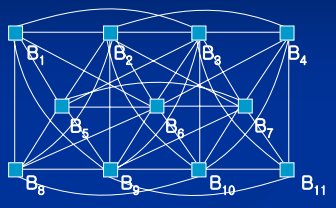
- Concurrent execution: Static pipeline

Concurrent Executions

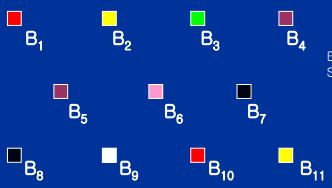


beacon coverage
= beacon interference range

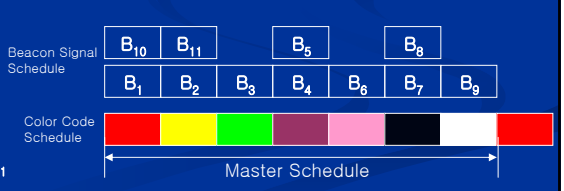
Beacon placement



Conflict graph

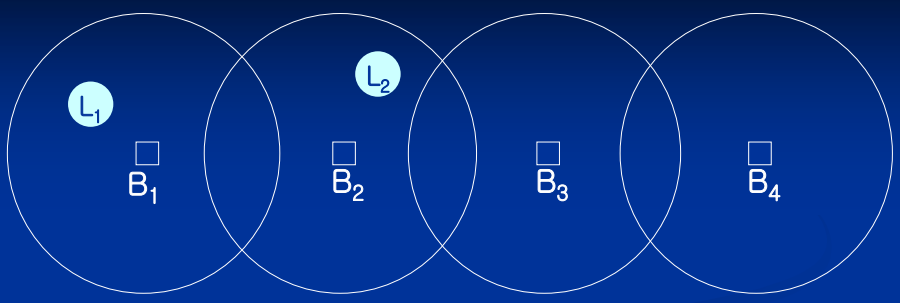


Color assignment

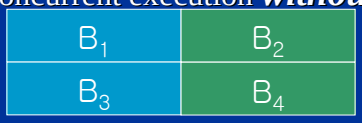


Static schedule of beacons

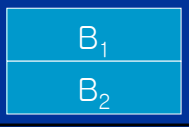
Location-aware



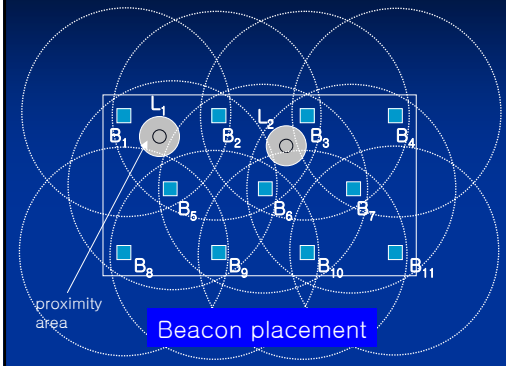
- Concurrent execution ***without*** location-awareness

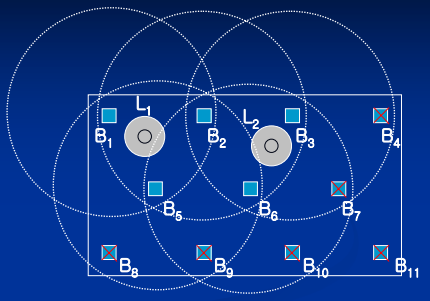


- Concurrent execution ***with*** location-awareness

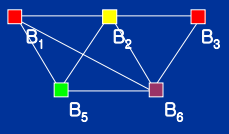


Location-aware scheduling





Minimal subset of beacons

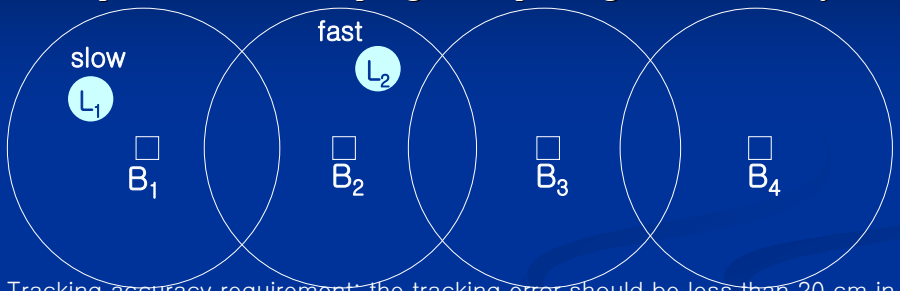


Location-aware conflict graph and coloring

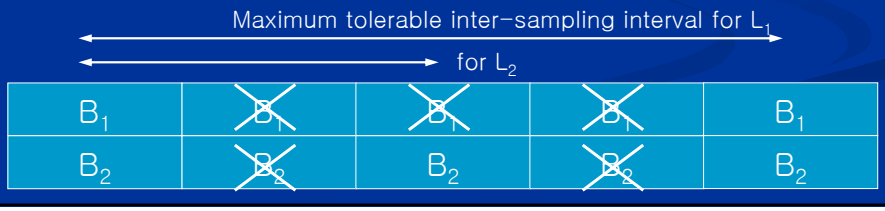
Location-aware schedule

Mobility-conscious

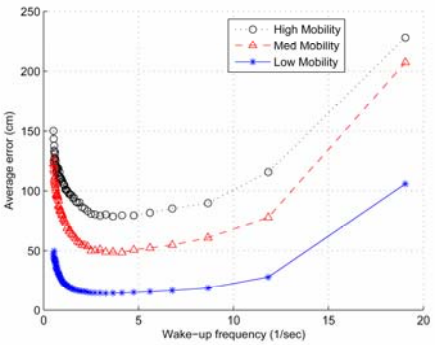
- Such high-frequency sampling is not always needed
- Adaptive control of sampling rate depending on user mobility



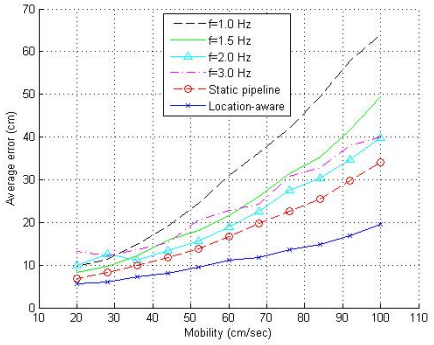
Tracking accuracy requirement: the tracking error should be less than 20 cm in 90% of times. (Transform application-requirement to temporal requirement)



Tracking Performance



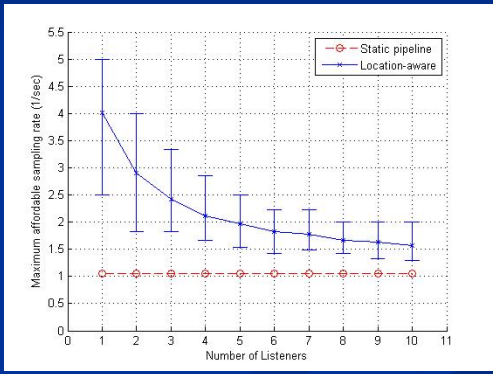
Fundamental Limit of Original Cricket Method



Improvement by Our New Method

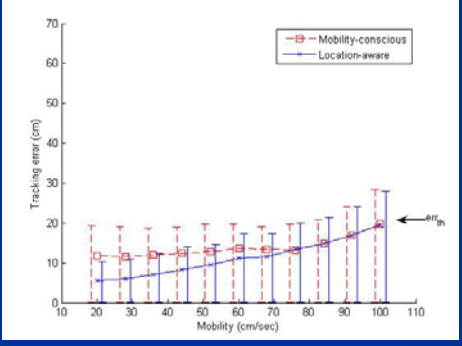
Location-aware Performance

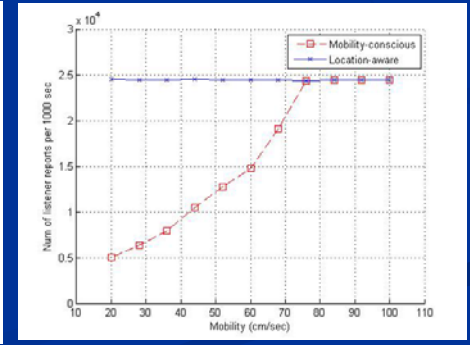
- By using Location-aware scheduling, we can achieve a higher sampling rate resulting in less error for high mobility listeners



Mobility-conscious Performance

- Tracking accuracy requirement: tracking error should be less than 20 cm with a probability higher than 90%
- Mobility-aware scheduling can meet the requirement while saving Listener's energy consumption.





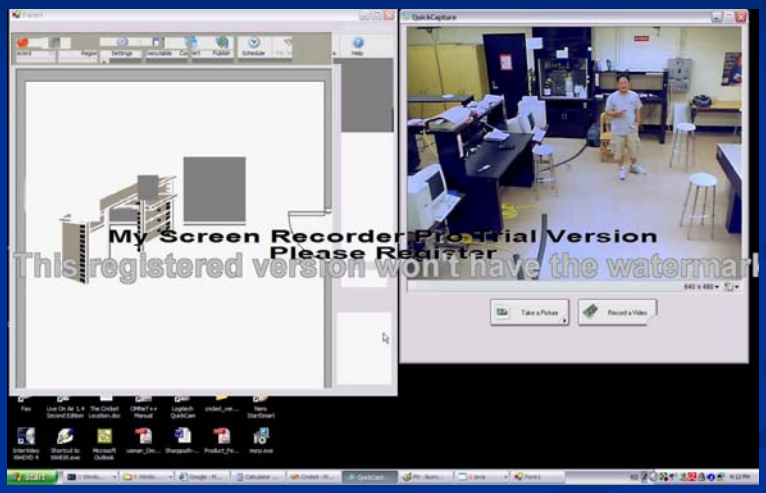
Slow Train Tracking (Original Cricket Method)

Slow Train Tracking (Our New Method)

Fast Train Tracking (Original Cricket Method)

Fast Train Tracking (Our New Method)

Tracking human

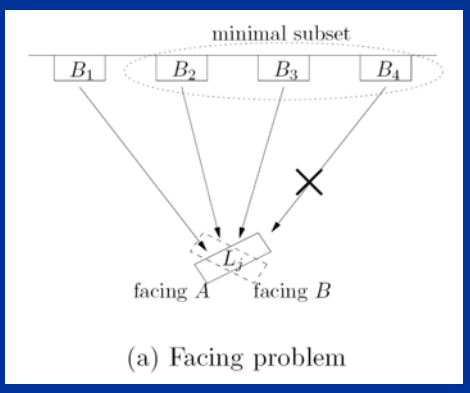


Tracking objects carried by human

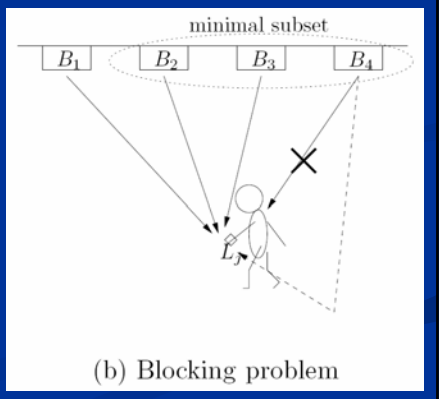
Finding object

Any Problem?

- Line-of-sight limitation of ultrasonic sensing



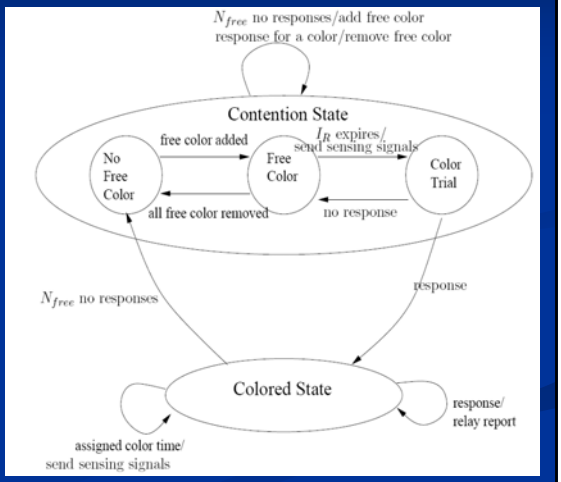
(a) Facing problem



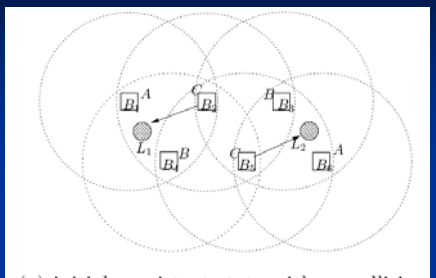
(b) Blocking problem

Success-based Self-Coloring

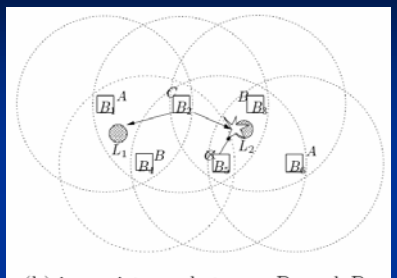
- Each beacon monitors which colors are free
- If at least one free color is detected, it tries to capture the color (contention based)
- Once it successfully capture the color, it senses the target in a contention free manner



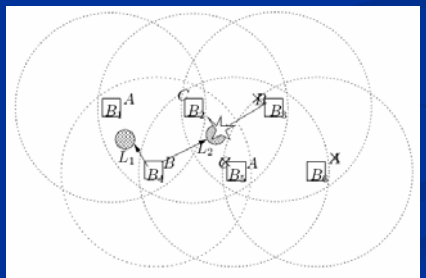
Coloring consistency



(a) initial consistent state with no collision

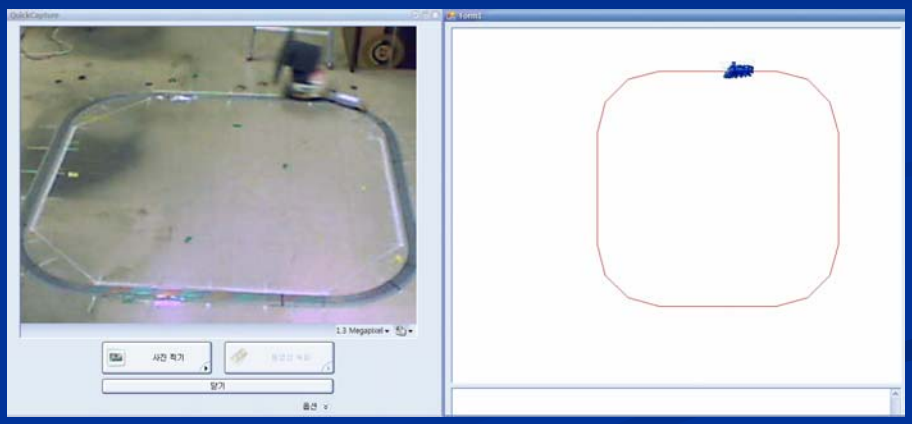


(b) inconsistency between B_2 and B_5

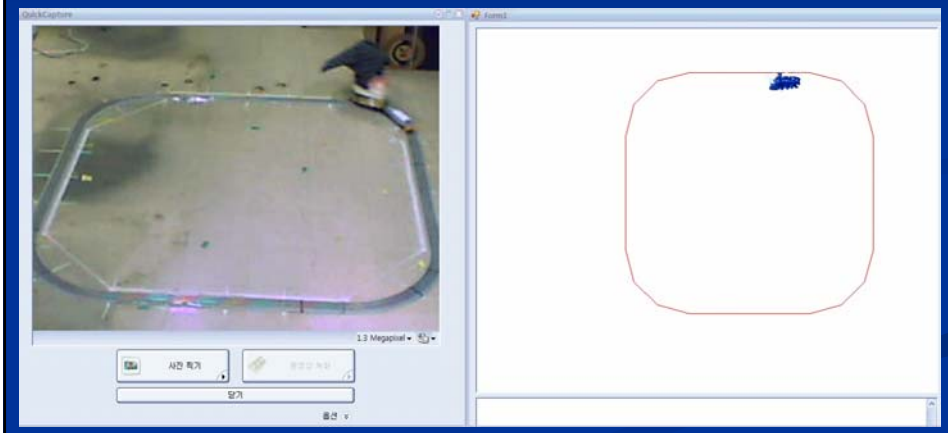


(c) inconsistency between B_3 and B_4

Location-aware scheduling (3-D Blocking Problem)



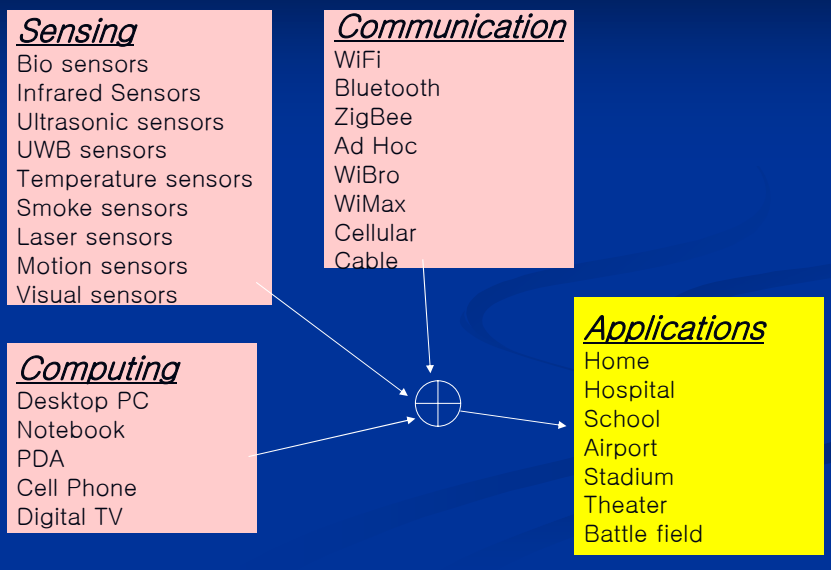
Self-Coloring Method (3-D Blocking Solved!)



Summary

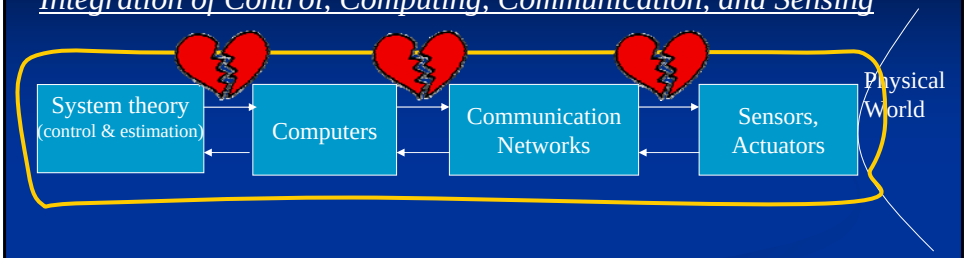
- Collision-free scheduling of sensing and communication for real-time tracking
  - Combined scheduling of sensing and communication
  - Location-aware scheduling
  - Mobility-conscious scheduling
- What we lean
  - Integration of sensing, wireless, computing, and estimation theory
  - Temporal requirement guarantee for physical interaction points

Tremendous Possible Applications



Scientific Challenge

Integration of Control, Computing, Communication, and Sensing



End-to-end timing behavior after integration?

System-wide Integration Theory of
Control, Computing, Communication, and Sensing
For Reliable, Evolvable, Real-Time Ubiquitous Systems