Privacy Sensitive Monitoring With a Mix of IR Sensors and Cameras

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1. Objective:

The objective is to show two sensor network technologies:

- spatio-temporal sensor net search through stored data
- reliable image transfer over low-speed sensor network

in a security/monitoring application for a building floor.

2. Demonstration:

Consider an installation which has an entrance and various private areas. The goal is to monitor the private areas to assist in prosecuting theft after-the-fact. Sensor nodes are equipped with cameras and PIR sensors. For privacy reasons, cameras are not deployed in private areas, however, they are considered acceptable for the entrance. Private areas have only PIR sensors, able to detect the presence or absence of a human. We assume sensors are deployed densely enough that a human moving through the sensor field triggers multiple sensors.

In regular operation, each sensor detects readings and stores the data locally. Ease of deployment requires mostly wireless, battery-operated nodes. Low-power requires that the data be stored locally (to flash memory) rather than sent to a central site.

If a theft occurs, nodes initiate a *spatio-temporal* search through the sensor net. The query originates at the node where the theft occurred and is tagged with the time (or times) of detections at that node. The query then is made against nearby nodes for any detections in the recent past. This query propagates through the network in space (moving from node to node) and time (adjusting the time window of interest). In this way we can establish a chain of events and track the intruder back to a sensor node which contained the intruder's picture.

When a chain of events is established from the point of theft to a node with a camera, the query has identified an image potentially correlated with that event. We then send that image over the sensor network to a display node.

3. Contributions:

This application demonstrates several sensor net technologies:

- Sensor network storage: sensor readings are stored in the network until needed, thus allowing sensor lifetime to be extended by reducing network communication. Storage uses a simple, application-specific local database.

- Spatio-temporal sensor net search: when data is needed, we perform a search through both space and time to map a chain of correlated events through the sensor net. This search is an application-specific service layered over directed diffusion [1].

- Reliable image transfer: most sensor network today send data unreliably over low-speed, energy conserving networks such as RFM or Chipcon radios, or they use traditional wireless networks such 802.11. In this application we use RMST, a reliable transport protocol suitable for sensor-network-specific networks [2].

4. References

[1] C. Intanagonwiwat, R. Govindan, and D. Estrin. "Directed Diffusion: A scalable and Robust Communication Paradigm for Sensor Networks." In *Proceedings of ACM/IEEE International Conference on Mobile Computing and Networking* ,pages 56-67, Boston, MA, USA, August 2000.

[2] Fred Stann and John Heidemann: "RMST: Reliable Data Transport in Sensor Networks." In *Proceedings of the First International Workshop on Sensor Net Protocols and Applications*, Anchorage, Alaska, USA, April 2003.

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Introduction: Applications and Technology

Application: balance privacy and security

- **Goal: Monitor building or areas**
  - Help prosecute theft in office environments
  - Monitor animals in natural habitat
- **But *don't* want cameras in every room**
  - Privacy concerns: people don't want to be watched everywhere.
    - People accept cameras in public areas like lobbies
    - Most don't want them in private offices
  - Cost and practicality: ubiquitous cameras expensive and difficult to deploy
  - **Our approach:** Augment cameras in lobbies with infrared sensors in hallways
    - Cameras can collect photos of people but only in public areas
    - IR sensors associate events (for e.g. theft), with place and time even in private areas
    - Challenge: relate IR-sensed events with camera photos, on demand

Technology: Demonstration of new sensor net technologies

- ***Spatio-temporal* search**
  - Use ***Directed Diffusion*** and stored readings.
  - Do processing only when needed, to save energy.
  - No transfer of data to central site.
- **Bulk image transfer**
  - Use ***Reliable Multi-Segment Transport (RMST)***, a reliable data transport layered over Diffusion.

Problem Description: Spatio-temporal search and reliable bulk transfer

Search through stored data in a sensor net

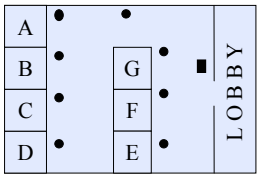
- **The scenario**
  - A building floor deployed with cameras, nodes and PIR sensors, stores information indicating when private areas are accessed.
- **The Problem**
  - To establish a ***chain of events*** tracking the movements of an intruder from site of theft to the entrance, where a picture of the intruder could be available.
  - All processing to be done only when needed i.e. after the theft.
  - No data transport to a central site. Save communication overhead.

Reliable image transfer over low-speed networks

- Demonstrate usability of RMST.
- RMST, a data transport protocol, layered over ***Directed Diffusion***, which provides reliability and fragment reassembly.
- Once an image which is potentially correlated to a theft is found, it is transmitted to a display node using RMST.

Proposed Solution: Recursive search using spatio-temporal queries

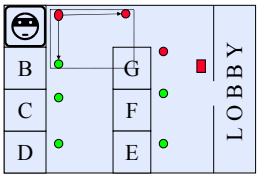
Observation Mode



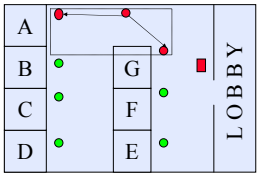
- Node with only PIR sensor
- Node with PIR sensor and camera

- **Layout of a typical building floor.**
  - A-G are private areas equipped with PIR sensors at entrance.
  - The lobby entrance is equipped with a PIR sensor and camera.
- **PIR sensors monitor private area occupancy.**
  - This is considered acceptable because there is no camera.
- **Camera photographs visitors when they enter floor**
  - This is considered acceptable, because lobby is public area.

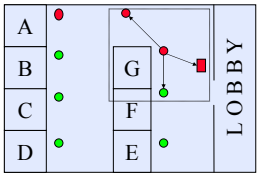
Search Process



- **Suppose theft occurs in A.**
  - Red nodes have events related to theft. Green nodes don't. Dotted rectangle shows region which receives query
  - A queries nearby nodes, tagging the query with its geographical location and time of theft.

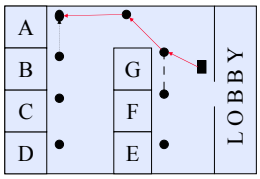


- **A receiving node, calculates a time window of interest and makes the query against local database.**
  - If it has matching events, it propagates the query tagging the query with appropriate timestamp and geographical information.
  - If there are no events, query is not propagated



- **Hence the query moves in time (adjusting time windows) and space (from node to node), and reaches the camera node**

Result



- **Red arrows indicate positive responses**
  - They are propagated to the initiator in this case A.
- **The dotted arrows indicate negative responses**
  - Negative responses are needed to ensure indicate receipt of query.
- After image is found, RMST is used to send image over sensor net.

Conclusion

- Demonstrates spatio-temporal search through stored data.
- Demonstrates reliable bulk image transfer using RMST.
- Architecture reduces camera deployment which reduces cost and increases privacy.
- Since data is not transferred to a central site, communication cost is reduced.

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