Distributed, Multimodal Sensor-data Fusion and Analysis

Edward Chang, August 7th, 2004

I. Overview

With the proliferation and advances of inexpensive sensing devices of optical (e.g., video cameras) and non-optical (e.g., electrical, thermal, and biological devices), it has become economically and technically feasible to configure a large network of sensing devices for collecting distributed information. In such a sensor network, sensors of different principles (modalities), with or without spatially and temporally overlapping coverage, generate multimodal signals. These signals need to be summarized as semantic events to allow efficient and effective queries for applications such as security surveillance [**WW03**], environment monitoring [**SO04**], supply-chain management, and health care [**Intel04**].

Many challenging research issues are involved in building sensors, configuring sensor networks, and developing models for managing and interpreting sensor signals. The contribution that the multimedia community can offer is our expertise in the areas of

- *Multimodal sensor-data management*,
- *Multimodal sensor-data analysis and interpretation*,
- *Sensor-data interaction*, and
- *Real-world system development and deployment*.

The opportunities are enormous. In the following sections, a few example problems are enumerated for inviting discussions and contributions.

II. Multi-modal Sensor-data Management

Sensing modalities include, but are not limited to, optical, mechanical, chemical, thermal, electrical, chromatographic, magnetic, biological, fluidic, ultrasonic and mass sensing [NSF04]. Signals generated by sensors of various modalities need to be sampled, filtered, compressed, transmitted, fused, stored, and indexed [**GO03**, **MW03**, **YG03**]. Each of these data-management steps must be conducted in an efficient way to conserve resources and power. The multimedia community is in particular interested in studying the multi-source, multimodal aspect of these data management issues. Traditionally, the multimedia community is strong in analyzing optical data; the community should also look into data other principles. Some research topics are *sensor-data representation*, *multimodal data-fusion techniques* [**WC04**], *energy-efficient data fusion* [**JC04**], *multimodal indexing*, and *information retrieval with multimodal sensors* [**BTG04**].

More specifically, what do we mean by the term *multimodality*? Take video surveillance as an example. A surveillance system using just one camera belongs to the charter of traditional *Computer Vision*. The multimedia community is interested in solving problems associated with multiple, heterogeneous cameras. Some example problems in multimodal surveillance are: *multi-camera data fusion*, infrared-, *thermal- or sound-guided video surveillance systems*, *video-guided remote surgical instruments*, *dynamic configuration of large-scale mobile camera networks*, *sensor-RF integrated systems for inventory control*, and *multi-sensor habitat monitoring*.

III. Multimodal Sensor-data Analysis and Interpretation

Sensor data must be mapped to semantics of interest for analysis, interpretation, and action. Such mapping requires effective statistical analysis tools [**KL02**]. In most actual deployment scenarios, sensors must operate in a hostile environment with limited resources. Therefore, an employed statistical method for analyzing and interpreting sensor events must be able to work effectively with limited resources and missing/noisy data. Some requirements to the statistical algorithms are

- One pass algorithm. Sensor-data may not be stored nor cached due to their volume. Most data can be "seen" just once by the algorithm.
- Real-time performance. Real-time action relies on real-time data analysis.
- Resource constrained computation. Restricted power, CPU cycles, RAM, disk space, network bandwidth are some computational constraints that the algorithm must observe.
- Noise and failure tolerant. Incomplete or uncalibrated data are norm in many sensor applications.

Example research problems in this area include: *multimodal decision theory for intelligent use of sensed information* [**WC04, DG04**], *detection and identification of false alarms*, *new statistical algorithms for multimodal sequence data learning* [**CJ04**], *sampling and filtering theories for sensor signals,* and *pattern recognition and state estimation under resource constraints*.

Specifically on *multimodality*, the work of [**DG04**] presents a multimodal sensor scenario where temperature can be inferred by voltage measurement. Taking advantage of this correlation between modalities can improve sensing accuracy and reliability, shown in the paper. Another example is infrared-, *thermal- or sound-guided video surveillance systems* mentioned in the previous section. It has been established that an infrared-camera can easily detect the eye location of a face to improve recognition accuracy on images taken by regular cameras.

IV. Human Sensor Interaction

This area pursues building human-sensor interaction models and methods. From human to sensors, the interaction system senses human intention [**SM04**]. From sensors to human, the interaction system provides tools to visualize sensors' states, diagnose and debug remote sensors, and configure and manage the sensor network.

V. Real-world System Development and Deployment.

We strongly encourage the development and deployment of real-world sensor applications, e.g., *biomedical health monitoring, diagnostic, and therapeutic systems*; *crisis management sensor systems*; *large-scale surveillance systems*; *tracking/monitoring of mobile units* (endangered species, inventory control, transportation); and *sensor assessment* (reliability, verification, validation).

References

[**BTG04**] R. Biswas, S. Thrun, and L. J. Guibas, A Probabilistic Approach to Interface with Limited Information in Sensor Networks, *IPSN*, pp.269-276, April, 2004.

[**CJ04**] E. Y. Chang, A. Jain, N. Panda, Y.-F. Wang, G. Wu, and Y. Wu, Managing and Mining Video-Sensor Data, UCSB Technical Report, July 2004 (submitted to *CIDR* 2005).

[**DG04**] A. Deshpande, C. Guestrin, S. R. Madden, J. M. Hellerstein, and W. Hong, Model-driven Data Acquisition in Sensor Networks, *VLDB* 2005.

[**GO03**] L. Golab and M. T. Ozsu. Issues in Data Stream Management. *ACM SIGMOD Records*, volume 32, San Diego, California, USA, June 2003

[**Intel04**] Intel Showcases Innovative Wireless Sensor Networks for In-Home Health Care Solutions, http://www.intel.com/pressroom/archive/releases/20040316corp.htm.

[**JC04**] A. Jain, E. Y. Chang, and Y.-F. Wang, Adaptive Stream Resource Management Using Kalman Filters, *ACM International Conference on Management of Data (SIGMOD)*, pp.11-22, Paris, June 2004.

[**KL02**] E. Keogh, S. Lonardi and W. Chiu, Finding Surprising Patterns in a Time Series Database In Linear Time and Space. In *the 8th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*. July 23 - 26, 2002.

[**MW03**] R. Motwani, J. Widom, A. Arasu, B. Babcock, S. Babu, M. Datar, G. Manku, C. Olston, J. Rosenstein, and R. Varma. Query Processing, Resource Management, and Approximation in a Data Stream Management System. In *Proceedings of the First Biennial Conference on Innovative Data Systems Research (CIDR)*, Asilomar, California, USA, January 2003.

[**NSF04**] NSF program solicitation 03-512, 2004

[**SM04**] Steven A. Murray, Human-Machine Interaction with Multiple Autonomous Sensors, Navy Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, California.

[**SO04**] Robert Szewczyk, Eric Osterweil, Joseph Polastre, Michael Hamilton, Alan M. Mainwaring, Deborah Estrin: Habitat monitoring with sensor networks. *Commun. ACM* 47(6): 34-40 (2004).

[**WC04**] Y. Wu, E. Y. Chang, K. C.-C. Chang, and John R. Smith, Optimal Multimodal Fusion for Multimedia Data Analysis, *ACM International Conference on Multimedia*, New York, October 2004.

[**WW03**] G. Wu, Y. Wu, L. Jiao, Y.-F. Wang, and E. Y. Chang, Multi-camera Spatio-temporal Fusion and Biased Sequence Data Learning for Video Surveillance, *In Proceedings of ACM International Conference on Multimedia*, November 2003.

[**YG03**] Y. Yao and J. Gehrke. Query processing for sensor networks. In *Proceedings of the First Biennial Conference on Innovative Data Systems Research (CIDR)*, Asilomar, California, January 2003.