Event Searching in the Real World

Takeshi Okadome*†, *Takuya Maekawa, Takashi Hattori, and Yutaka Yanagisawa

Abstract

We describe a system that, in an environment in which a sensor network constantly collects data produced by sensors attached to physical objects, searches for data segments corresponding to real-world events using natural language words in a query. The system translates each query into a physical quantity representation, searches for a sensor data segment that satisfies the representation's description, and replies to the query by giving the event's occurrence time and place or objects related to it. It is constructed as an application for the "s-room", a project that aims to search for or retrieve specific events that occurred in the real world.

1. Introduction

In applications based on sensor networks that monitor the physical world and detect events occurring in it, events are named according to attributes that have scalar values or ranges of scalar values, such as temperature and light levels. Such an event, which is described in a language similar to SQL (structured query language), such as TinyDB [1] or Couger [2], is characterized by the value of a particular sensor reading. The event descriptions given by these languages enable surveillance applications to provide services that are activated by the occurrence of certain events. The languages, however, describe only events that can be represented using values from sensor readings. Thus, humans can neither naturally represent an event using the languages nor intuitively understand the event represented by the descriptions.

This paper describes a system [3] that facilitates human-centric searching of events that occurred in the world. Instead of requiring queries related to sensor reading values, this system embedded in a sensor-networked environment permits us to ask the environment itself questions such as "who drop vase" or "when door open". Using a method that grounds* sensor data, the system translates such queries into descriptions using a representation based on natural language phrases for specifying events that can be detected from the sensor data. This system is constructed as an application for the "s-room", which is a project that aims to search for or retrieve specific events that occurred in the real world on the basis of sensor-networked environments.

2. Event representation

As an intermediate language between event description using natural language (NL) and the values of the sensor readings, we design a representation consisting of NL phrases.

2.1 Observable events

WordNet [4] is an electronic lexical database in which English nouns, verbs, adjectives, and adverbs are organized into synonym sets, with each representing one underlying lexicalized concept, with different relationships linking the sets. This means that we can use WordNet to construct a representation. That is,

† NTT Communication Science Laboratories
Soraku-gun, 619-0237 Japan
Email: houmi@idea.brl.ntt.co.jp

* Ground: This term is used here, by analogy to electrical grounding, to denote giving the correspondence between a word and its meaning.

we can follow the strategy of collecting as many English words or phrases that denote physically observable events as possible using WordNet. We collect "observable" event concepts in the following way.

First, as seeds we set the twelve words: move, reach, pass, exit, touch, enter, rise, drop, keep, increase, decrease, and remain. Starting from the seed words, we traverse synonym links in WordNet and choose observable synonyms. We assume that synonyms that have the same meaning denote the identical event concept. We tag the concept with connected words that make up a phrase that describes the meaning written in WordNet; for example, the words shift, dislodge, and reposition denote the event concept of a change in direction. Therefore, we deal with them because they denote the concept, which we label with the phrase-like word change-direction.

This procedure offers us an efficient synonym selection method that leads to the effective construction of a set comprising 185 labels (event concepts) and 348 words associated with the labels. We call the labels denoting event concepts the *event descriptors*.

2.2 Expression using physical quantities

As a first approximation, we assume that it is possible to assign the following simple form to each observable event:

$$\forall t((t_0 \le t < t_1 \to P_1) \wedge (t_1 \le t \le t_2 \to P_2) \wedge (t_2 < t \le t_3 \to P_3)),$$

where t_0, t_1, t_2, and t_3 are free variables and P_1, P_2, and P_3 are mathematical expressions including variables and physical constants that denote physical quantities such as position and temperature. In this form, the expression $t_0 \le t < t_1 \to P_1$ represents the *precondition* in which t is a parameter denoting time and P_1 expresses the physical state of objects connected with the event before the event occurs. The expression $t_1 \le t \le t_2 \to P_2$ specifies the *ongoing condition* in which the event starts at t_1 and finishes at t_2, and P_2 denotes the state change of the physical object. The final expression $t_2 < t \le t_3 \to P_3$ describes the *post-condition*. The event lasts until t_3, as expressed by P_3.

The assumption enables us to assign the same form to event descriptors. For example, we assign the event descriptor go-from-region-to-region (regions: ρ_1 and ρ_2) to the following expression:

$$\forall t((t_0 \le t < t_1 \to D(\lambda(t), \rho_1) = 0) \wedge$$
$$(t_1 \le t \le t_2 \to \left|\frac{d\lambda(t)}{dt}\right| > 0 \wedge D(\lambda(t), \rho_2) > 0) \wedge$$
$$(t_2 < t \le t_3 \to D(\lambda(t), \rho_2) = 0)),$$

where $D(\rho_1, \rho_2)$ denotes the distance between the regions and $\lambda(t)$ is a special coordinate in a three-dimensional system at time t of the object that goes from one region to another.

3. Event searching system

An overview of our system [3] is shown in **Fig. 1**. It consists of two modules: a query module and a search engine that refers to the sensor data grounder. We assume that our system operates in an environment in which a sensor network always collects data produced by sensors attached to physical objects. The system returns information about an event that

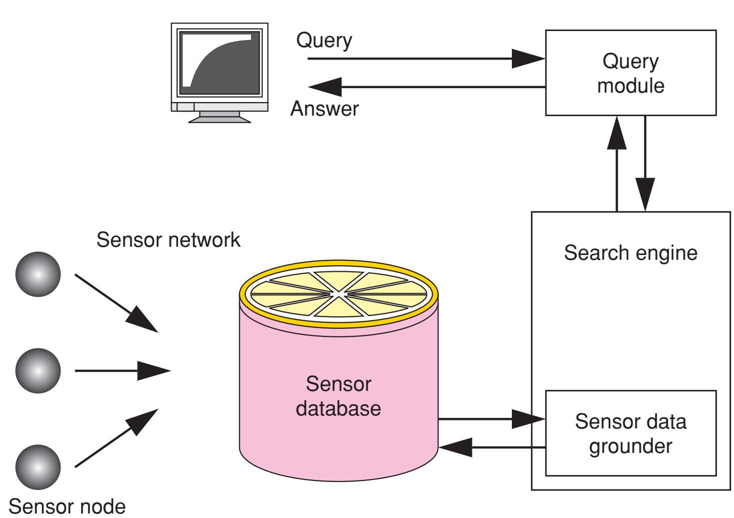

Fig. 1. Overview of the event searching system.

matches an intuitive interpretation of a set of NL words in a query.

The query module reads a query, which is a set of English words just like those used in Google, and translates the set into event descriptors and extracts their assigned physical quantity expressions. The search engine searches the sensor database by contacting the sensor data grounder, which finds a data segment that satisfies the physical quantity expression. The query module can also answer by, for example, displaying a video image recorded by video cameras.

Beginning with the most recently saved data, the sensor data grounder checks the data in a chunk whose length can be adjusted by a parameter until it finds or fails to find a data segment that satisfies the physical quantity expression assigned to the observable events.

Let the physical quantity expression assigned to an observable event be $\forall t((t_0 \leq t < t_1 \rightarrow P_1) \wedge (t_1 \leq t \leq t_2 \rightarrow P_2) \wedge (t_2 < t \leq t_3 \rightarrow P_3))$. Starting from the latest collected data and proceeding to the older data, the sensor data grounder seeks a continuous data segment within the segment length ranges that correspond to those of the time intervals, $t_1 - t_0$, $t_2 - t_1$, and $t_3 - t_2$. The sensor grounder judges that the observable event occurred between t and t' if and only if P_1, P_2, and P_3 hold for a data segment within the respective ranges of the intervals and $t' - t$ is within the range of $t_2 - t_1$ for the data segment.

To demonstrate this system, we applied it to a sensor-networked office environment called the s-room in which physical objects are equipped with sensor nodes containing (i) microsensors such as a triaxial accelerometer, thermometer, hydrometer, illuminator, and human detector and (ii) wireless networking and computing engines for communicating with computing servers and other networked embedded objects such as the sensor database. The system permits us to ask queries concerning an object and an event such as "when door open." It returns an answer such as "1st October, 2006 13:14:10".

4. Related work

Yap, Srinivasan, and Motani [5] proposed a system that allows humans to search for and locate physical objects as and when they need them. Under the assumption that all physical objects can be tagged with small devices that possess limited processing and communication capabilities, the system provides location information in NL sentences that offer references to identifiable landmarks, rather than to precise coordinates, such as "my notebook is on my desk" or "the keys are on the dining room table".

The event-driven distributed model of the context-aware system proposed by Tan et al. [6] is leveraged on the event specification language and composite event detection algorithm. They classify events into primitive events and composite events that are constructed recursively by applying some operators to primitive and composite events. Primitive events are those low-level events that can be directly detected by sensors or other mechanisms embedded in the computing entities in the system. Composite events are events that are formed by applying a set of event operators such as "or", "and", or "seq(;)" to primitive and composite events. They also extend the context model with an event ontology so that event information can be retrieved from the infrastructure in a consistent and semantic way using SQL-like, rather than NL-like, semantic queries such as SELECT ?X WHERE (?X owl:hasTimeOfOccurrence>, "20.05.04 13:00:41").

References

[1] S. Madden, M. J. Franklin, J. M. Hellerstein, and W. Hong, "The design of an acquisitional query processor for sensor networks," In Proc. of the ACM SIGMOD Conference (SIGMOD2003), pp. 491-502, 2003.

[2] P. Bonnet, J. Gehrke, and P. Seshadri, "Querying the physical world," IEEE Pervasive Communication, Vol. 7, pp. 10-15, 2000.

[3] T. Okadome, T. Hattori, K. Hiramatsu, and Y. Yanagisawa, "A Real-World Event Search System in Sensor Network Environments," 7th International Conference on Mobile Data Management (MDM'06), p. 62, 2006.

[4] C. Fellbaum, ed., "WordNet: An Electronic Lexical Database," MIT Press, 1998.

[5] K. K. Yap, V. Srinivasan, and M. Motani, "Max: human-centric search of the physical world," In Proc. of the 3rd ACM Conference on Embedded Networked Sensor Systems (SenSys2005), pp. 166-179, 2005.

[6] J. G. Tan, D. Zhang, X. Wang, and H. S. Cheng, "Enhancing semantics spaces with event-driven context interpretation," In Proc. of the 3rd International Conference on Pervasive Computing (PERVASIVE2005), pp. 80-97, 2005.

Takeshi Okadome

Senior Research Engineer, Group Leader of Ambient Semantics Research Group, Innovative Communication Laboratory, NTT Communication Science Laboratories.

He received the B.S., M.S., and Ph.D. degrees in computer science from the University of Tokyo, Tokyo, in 1983, 1985, and 1988, respectively. During 1988-2000, he worked in NTT Basic Research Laboratories. After a two-year stay at Advanced Telecommunications Research Institute International, he is now with NTT Communication Science Laboratories. He has been involved in research on computer science and human science. His current interests are the study of real-world semantics in sensor-networked environments.

Takuya Maekawa

Researcher, NTT Communication Science Laboratories.

He received the B.E., M.S., and Ph.D. degrees in computer science from Osaka University, Osaka, in 2001, 2003, and 2006, respectively. He joined NTT in 2006. His interests are ubiquitous computing environments and web technologies in mobile computing environments.

Takashi Hattori

Researcher, NTT Communication Science Laboratories.

He received the B.S. degree in mechanical engineering and the M.S. degree in system engineering from Kyoto University, Kyoto, in 2002 and 2004, respectively. He joined NTT in 2006. He has been involved in research in ontology development for everyday-life environments.

Yutaka Yanagisawa

Research engineer, NTT Communication Science Laboratories.

He received the B.S., M.S., and Ph.D. degrees in computer science from Osaka University, Osaka, in 1993, 1995 and 1997, respectively. He joined NTT in 1997. His current interests are computer science, database systems for moving objects, and ubiquitous computing environments.