Project Pervasive Association: Toward Acquiring Situations in Sensor Networked Environments

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Summary
Aiming to automatically acquire situations for context-aware services, project Pervasive Association focuses on such incremental situation changes as when a new computer is brought into an office. The following statements capture its goal: ``when a new entity enters an environment, infer what the entity is," and ``when a thing in an environment has a new role, infer what the role is."
Pervasive Association assumes a world in which a sensor node, which is equipped with (a) microsensors and (b) wireless networking and computing engines for communication with computing servers and other networked embedded objects, is attached to physical objects. Approaches to the goal consist of solving the inverse symbol grounding problem, constructing real-world knowledge, and providing a situation and context inference method.
Key words: real-world semantics, sensor network, situation

1. Introduction

Many systems and applications that provide context-aware services are required to detect the locations of persons and artefacts to acquire and maintain situations and contexts. The Sentient Computing project [1], for example, develops systems that can change their behavior based on a model of the environment constructed using sensor data; objects in the model contain up-to-date information about locations and the state of corresponding real-world objects. The project bears the following characteristics:

1) ascertaining object positions at near human levels of accuracy requires a specially designed sensor system known as the Bat location sensor system;
2) sentient computing systems do not need to be intelligent or capable of forming new concepts about the world.

Originally, Weiser [2] emphasized the need for location detection to realize ubiquitous computing without requiring even a hint of artificial intelligence. Many studies have attacked the location issue, but detecting location is still a crucial problem.

On the contrary, the Smart-Its project [3] challenges the integration of diverse simple sensors as alternatives, aimed at awareness of situational contexts that cannot be inferred from location and targeted at resource constraint device platforms that typically do not permit visual context processing. The project is investigating multi-sensor context-awareness to develop a number of device prototypes that include an awareness module used to augment mobile phones, Mediacup [4], which exemplifies context-enabled everyday artefacts and the Smart-Its platform for aware mobile devices. The project tries to highlight the substantial challenges for perception techniques to perform in low-end computing environments.

In particular, aiming at facilitating applications in which artefacts cooperatively assess their situation in the world without requiring supporting infrastructure, Strohbach [5] introduced an architecture and system for Cooperative Artefacts that modeled their situation on the basis of domain knowledge. Their approach foresees the instrumentation of artefacts with sensing, computing, and networking, thus facilitating applications that are fully embedded within artefacts and independent of any infrastructure in the environment.

They investigated their concept and technological approach in the context of chemical processing to ensure that it is developed against real needs and under consideration of realistic constraints. They specifically explored the storage of containers with chemical materials.

Along a similar approach to context-awareness, project *Pervasive Association* is studying real-world ``semantics" to develop a system that makes a smart object ``smarter" and enables things or a set of things to infer situations using sensor data and relations between things based on real-world knowledge.

In particular, focusing on the ontological roles of things and relations between things, the project envisions a sensor network equipped with a situation (and context) inference function without accurate location detection. (For the work of a sensor network, see Estrin et al. [6] and Kevin [7]; See also Akyildiz et al. [8] for a survey.) This article describes the aim, the goal, and the approach of the project.

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2. Aims and Goals of the Project

The challenges of large-scale ubiquitous computing require a structured and flexible approach to situation and context[*], which are, however, not simply the state of a predefined environment with a fixed set of interaction entities; they are part of a process of interaction with an ever-changing environment [9]. Let us here consider when a situation changes. The current situation is usually altered by a change in the number of entities (when a new personal computer is brought into an office), or a change in the role assigned to an entity (when a thick book is used as a pillow), or a change in the relations between two entities (when a book is from a bookshelf).

Focusing on such incremental changes of situations, we aim to automatically acquire the physical entities, roles, and relations from which situations and contexts emerge.
In particular, we deal with situation changes: ``when a new entity enters an environment" and ``when an entity in an environment has a new role," and set the following goal:

1. For a new entity (called an ``unknown thing"), we infer
    a) what the entity is
    b) its role
    c) its relation with another entity in the environment
2. For an entity that has a new role that differs from its original one, we identify
    a) what the new role is
    b) its new relation with other entities in the environment

We assume a world in which things (physical entities) have a sensor node equipped with (a) microsensors and (b) wireless networking and computing engines for communication with computing servers and other networked embedded objects. Based on this assumption, we develop a system that infers the name of an unknown thing, its role, or its relation with another entity. The system assumes an everyday environment such as an office or a laboratory where a sensor node is attached to all ``known" artefacts. The sensor node to which we attach things is equipped with the following features:

a) sensors such as an accelerometer, a thermometer, a hygrometer, or an illuminometer, which are expected to be smaller and cheaper in the future;
b) a processor and memory for computation;
c) connections with each other through a network; and the ability to dispatch the names of things.

In this environment, we also attach the same sensor node to an unknown thing except that neither the system nor the sensor node knows what the thing is.
Developing such a system leads us to the following issues:

1) establishing a guide for designing a knowledge base of the real-world;
2) constructing an inference system; and
3) finding relations between sensor data and linguistic symbols.

We will also build an office or a laboratory as a test site for our developed technology. Note that we do not necessarily assume that we can detect the accurate location of a thing.

3. Approach

Using only the names of known things and data from sensors attached to known and unknown things, we cannot determine the name or roles of an unknown thing, unless we assume some additional constraints. Coping with indeterminacy at least requires us to use the properties of things and their relations.

Beginning with an existing ontology such as WordNet [10], we extend it to include machine-readable, real-world knowledge about what roles things have and what relations things have with others, which existing ontologies do not have.

We express ontology extension by English lexicon because WordNet represents the specification of concepts by English lexicons and some relations between concepts such as ``part-of" or ``is-a."[+] Using (English) symbols enables us to easily debug the extension and to use various inference techniques previously developed in symbolic manipulation frameworks.

Inference on the symbolic level, however, introduces another problem; it requires the symbolization of sensor data based on the relation between sensor data and linguistic symbols that must be clarified.

Accomplishing our goal thus requires us to tackle the following challenges:

1. We must specify the relation between sensor data and linguistic symbols and translate sensor data into linguistic symbols using the relation. This is a kind of

[*] According to Coutaz et el. [9], this article defines context and situation as follows. A *context* is defined by a set of entities (typically including literal values as well as real-world and information objects), a set of roles (for example, functions) that entities may satisfy, a set of relations between entities, and a set of situations. *Situations* denote specific configurations of entities, roles, or relations.

[+] In general, ontologies are expressed by words of a natural language and relations between concepts.

a symbol grounding problem and its inverse that is a sensor fusion problem.

2. We must establish a universal guiding principle for constructing real-world knowledge. Following the principle, we will build real-world knowledge about what roles things have and what relations they have with others.
3. Using linguistic symbols translated from sensor data and real-world knowledge, we infer the name of an unknown thing, its roles, or its relation with other entities. We also infer a new role that differs from a thing's original role.

The project deals with the issues in the following approaches.

1. Attacks on the (inverse) symbol grounding problem consist of the following three steps.
    a) We formulate a forward-mapping system for expressing linguistic symbols by physical quantities.
    b) We specify the relation between physical quantities and sensor data.
    c) We construct inverse mapping from sensor data to linguistic symbols using a forward-mapping system and the relation between physical quantities and sensor data.

   We also take another approach to the problem. That is, we investigate a method of describing the world by a few primitive relations, each of which is detected by sensors. For a preliminary study of description by primitives, see Yanagisawa et al. [11].
2. To establish a guiding principle for constructing real-world knowledge, we focus on the interactions between a person and a thing. We refer to a human motion analysis method [12] and expand it, obtaining a ``minimal" set of motion expressing symbols to specify a thing's roles and relations with others. We are currently examining whether the 21 motion symbols, such as ``grasp" and ``release load" that we have selected, cover sufficient roles of things and relations between things [13].
3. For inference, we need to introduce a kind of ``convincing measure" into the inference process or a probabilistic inference method at the first-ordered predicate logic level. Sensor data and real-world knowledge contain insufficient information to determine a thing's name, its roles, and relations between others.

Furthermore, to demonstrate the methods and principles experimentally, we are developing:

1) experimental rooms, an office and a laboratory, equipped with a sensor network;
2) several types of sensor nodes and a sensor data management system; and
3) service applications.

We have already designed and developed sensor node prototypes and a sensor data management system [14].

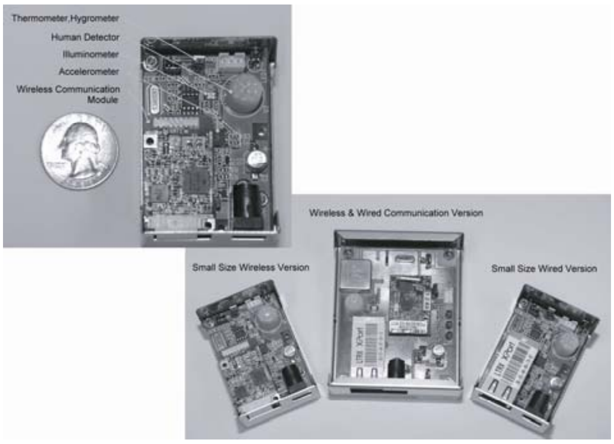

Fig. 1. Prototypes of sensor nodes.

Figure 1 shows the sensor node prototypes equipped with a thermometer, a hygrometer, an illuminometer, an accelerometer, and a human detector that senses infrared. The prototypes also have an embedded CPU, an Ethernet interface module, and/or a wireless communication module.

Figure 2 illustrates the architecture of the proto-type of a sensor data management system The sensor data management system prototype consists of gateway daemons, a data pipe, a sensor process, a database process, and an application process. One key feature provided by the sensor data management system is encapsulation of the sensor devices and databases in which the sensor data are stored. Encapsulation permits us to program applications without bothering with such device details as boot sequence and sensing parameters. The system also simplifies communication protocols by establishing data pipes for exchanging sensor data among processes.

Besides the sensor nodes and the sensor data management system and databases, our system will have an ontology server and an inference server connected to the sensor databases through a network.

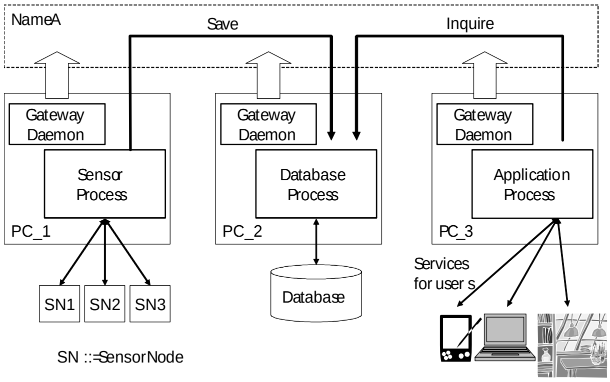

Fig. 2. Sensor data management system

4. Discussion

The automatic inference of situation and context enables us to introduce an independent layer between the sensor network and the application layers. The introduction of this layer corresponds to provide middleware that infers a situation and a context from sensor data and maintains them. Such public middleware provides economy in program development and facilitates cooperation among components as well as consistent behavior across applications [9]. Note that the layer introduced here consists of two sublayers: an inverse symbol grounding layer and a situation and context inference layer.

We focus on situation changes that form a dynamic aspect of situation and context. Besides a situation change, the automatic construction of situations and contexts requires the extraction of person's actions (and sometimes identity). Note that a thing's role (function) and a person's action (motion) using the thing are two sides of the same coin. We thus expect that exploring ontology by the guiding principle with which we specify a thing's role by motion expressing symbols will lead to new technologies for extracting a person's behavior (and identifying a person).

Source-tagging is an application of Electronic Article Surveillance labels into products or packaging during the manufacturing or packaging process. If all products are source-tagged by manufacturers, then we need not infer a thing's name and its properties, which are dispatched by the tag attached to the thing. During the manufacturing process, however, we cannot register such information as relations between a tagged thing and other things in daily usage because people use a thing in various ways. Furthermore, in some cases we cannot obtain source tagging support. Thus, our developed method for attaining our goal serves to automatically identify situations and contexts.

5. Envisioned Application

Theories, guiding principles, and technologies developed to realize ``smarter objects'' are expected to lead to the development of this study. Let us here describe some examples.

1. Assume that small sensor node and wireless ad hoc network technologies are established. Then, for example, as an extension of an adhesive paper label such as Post-it*, we can use a light, thin, adhesive IC-tag and attach it to an everyday thing. After the tag is attached to a thing, without human assistance, it acquires the thing's name and functions and dispatches them.
2. The RFID industry has suggested a variety of solutions to address the dangers posed by RFID tagging of consumer products. Among them are killing the tags at point of sale, rendering them inoperable. Using the technology which we develop enables us to reconstruct the name and functions of a tagged thing and to achieve its full potential.
3. As a development of monitoring environmental conditions by scattering grain-of-sand sized nodes, a scattered node, which happens to land on a thing (or a person) and becomes attached to it. Now it can dispatch a thing's name and its functions in addition to such sensor data as the temperature and moisture around it. This leads to monitoring environmental conditions more accurately and controlling them more effectively.
   a) It serves to optimize crop production, for example, and
   b) it enables us to distrimine automatically garbages including kitchen refuse.
4. The technologies that extract a person's behavior or specify identity enable us to specify a person displaying suspicious behavior; for example,
   a) to specify a person displaying his/her suspicious behavior and this serves to prevent crimes and
   b) to identify a terrorist and this leads us to eliminate terrorism.
5. By specifying animal species or specific individuals, we can discover the path of infectious diseases carried by animals, such as avian influenza, and prevent infection; we can also grasp the behavior of diverse animals in their habitats, which leads to the protection of natural environments.

* Post-it is a registered trademark of 3M.

6. Related Work

The work that most resembles our Pervasive Association is the Smart-Its project described in Section 1. Let us here describe some other projects that seek to exploit new technological advances that embed sensing and computing with communication capabilities by networks in all sorts of objects in an environment.

The Smart Kindergarden project [15] envisions a system that provides a childhood learning environment individualized to each child; it adapts to the context, coordinates activities for many children, and allows unobstrusive evaluation of the learning process by teachers. The project plans to construct a system using wirelessly-networked, sensor-enhanced toys with back-end middleware services and database techniques.

To realize the system, the project has established the following two goals:

1) investigation of research challenges in wireless networking, middleware services, and data management essential for realizing a scalable information infrastructure;
2) experimental exploration and evaluation of this technology in the context of the concrete application domain of early childhood education.

Tokuda Laboratories at Keio University has developed Smart Furniture, which extemporaneously converts legacy non-smart space into a Smart Hot-spot that consists of computational services [16].
Since Smart Furniture is equipped with networked computers, sensors, and various I/O devices, it can provide various services alone or by coordination with other devices.

Aoyama and Morikawa Laboratories at the University of Tokyo envision ``3C everywhere" (``Computing everywhere," ``content everywhere," and ``connectivity everywhere") and ``physical interaction" (that denotes connecting the physical world with pervasive networks of sensor-rich and embedded computation) as a future networked environment [17]. Their project has developed a sensor node called U3 that have developed a sensor node called U3 that communicates with other nodes via a wireless medium.

They constructed a system that generates dynamic context-aware services based on user preferences and habits [17]. The system records all user activities and consumed services and creates a stochastic model of them. The project has also developed a contextual data management platform that allows the separation of applications and sensing.

Compared with these projects, our Pervasive Assosiation bears the following characteristics:

(a) it aims to establish a *universal* guiding principle for constructing real-world knowledge, and
(b) it tries to design intermediate representation between sensor data and linguistic symbols such as a representation of linguistic symbols by physical quantities. The characteristics are expected to permit the construction of context-aware applications in various ubiquitous environments.

7. Concluding Remarks

Aiming to automatically acquire situations, project Pervasive Association has set the following goals: ``when a new entity enters an environment, infer what the entity is," and ``when an entity in an environment has a new role, infer what the role is." Our approach tackles those goals by solving the inverse symbol grounding problem, constructing real-world knowledge, and providing a situation and context inference method. The technologies developed by confronting the issues afford a foundation on which to provide context-aware services and task support for people in homes, offices, laboratories, and any other environments. They will also serve to cope with such social issues as environmental disruption, protection of nature, food crises, crime prevention, and counter-terrorism measures.

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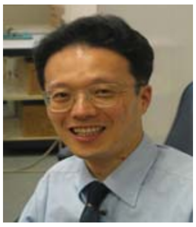

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