A Multi-Agent Service Framework for Context-Aware Elder Care

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Abstract. Advances in healthcare have led to longer life expectancy and the so-called aging population trend. The cost of caring for the elderly is rising progressively and threatens the economic well-being of many nations around the world. Instead of professional nursing facilities, many elderly people prefer living in their own homes independently. To enable successful aging in place, this research explores the roles of technology in improving the quality of life while reducing the cost of healthcare to the elder population. In particular, we propose a multi-agent service framework, called Context-Aware Service Integration System (CASIS), to integrate event-driven services with the OSGi service platform. This paper presents several context-aware service scenarios that have been developed on the proposed framework to demonstrate how context technologies and mobile web services can help enhance the quality of care for an elder's daily life.

1 Introduction

Advances in healthcare have led to longer life expectancy and the so-called *aging population trend*. Statistics in Taiwan show that the elderly population (persons 65 years old and over), is expected to rise steadily from 8.5% of the population in 2000 to 9.9% of the population in 2010. In the United States, the elderly population has grown 10-fold within the last century. According to projections by the US Census Bureau, about 1 in 5 Americans would be elderly by the year 2030, compared with about 1 in 8 Americans in 1994. In addition, over 80% of the elderly suffer at least one chronic condition, and 50% have at least two [1]. Statistics also show that an increasing number of young adults, traditionally the main carers of their elders, live apart from their elder family members. In Taiwan, the percentage of elderly living with their children has declined steadily from about 61% in 1992 to 51% in 2002. Similar social trends occur throughout the world, resulting in progressive rise in the cost of elder care, and threatening the economic well-being of countries worldwide. Many elder people prefer living in their own homes without caretakers, so they can enjoy an *independent* lifestyle.

To enable *successful aging in place*, this research explores the roles of intelligent sensing, wireless communication, mobile and ubiquitous computing in healthcare services for the elderly. This paper introduces the Context-Aware Service Integration System (CASIS), which is an event-driven service-oriented system framework integrating web services and OSGi platform. In addition to providing context-aware healthcare services to the elderly resident in the intelligent space, the proposed framework allows remote caretakers, such as concerned family members and healthcare providers, to closely monitor and attend to the elder's physical and mental well-beings anytime, anywhere. Technology has eliminated the "geographical distance" between the elders and their caregivers to achieve higher quality elder care.

The smart environment interacts with the elder through a wide variety of appliances for data gathering and information presentation. The environment tracts the location and specific activities of the elder through sensors, such as pressure-sensitive floors, cameras, bio-sensors, and smart furniture. Meanwhile, the elder receives multimedia messages or content through speakers, TV, as well as personal mobile devices. The caregivers may access the elder's health and dietary information through any web-enable device like a PC or PDA. *Context-aware computing* enables the environment to respond at the right time and the right place, to the elder's needs based on the sensor data collected. The environment is further equipped with integrated control for convenience, comfort and safety. The system infers the status of the elder and performs appropriate actions. For example, upon sensing that the elder has fallen asleep, it turns off the TV, and switches the telephone into voice mail mode. It informs and plays back any incoming messages when the elder wakes up.

In this paper, we will present several context-aware services for elder care, and describe the proposed multi-agent service platform. Section 2 defines our vision of *context-aware elder care* and introduces the enabling technologies. Section 3 presents the proposed system architecture and key components. Implementation issues are given in Section 4. Section 6 reviews some important work in elder care and intelligent space, followed by the conclusion in Section 7.

2 Context-Aware Elder Care

This section starts by presenting a sample scenario for elder care, as well as our vision on how technologies can promote a convenient and healthy lifestyle for elders living independently.

2.1 A Sample Scenario: Before and After

Mr. Chang, aged 69, lives in his home town by himself while his grown children have moved to different locations. Chang is a diabetic and needs to test his blood glucose level several times a day. His physician requests Chang to keep a record of the test results, which are reviewed during the monthly checkups. In order to keep his diabetes under control, the doctor orders Chang to follow a strict diet with meals designed by his dietician.

Many elderly people have a hard time keeping up with their health regime. Like most elders suffering from chronic diseases, Mr. Change requires routine medication, which may be adjusted periodically by his physician according to his health conditions. Sometimes, Mr. Chang forgets to take his medicine on time. At other times, he gets confused about the prescribed dosage. It is also difficult to manage Chang's diet. Chang enjoys *good food*, and considers his diabetic diet overly restrictive. As a result, he tends to make poor food choices. However, there is no way for his dietician and family to monitor Chang's dietary behavior.

Many aspects of elder care can be improved with the help of intelligent space technology, including sensors, context-aware reasoning and web services. Now, let us imagine an updated scenario in which Mr. Chang lives alone in a smart house under the care of the Context-Aware Service Integration System (CASIS). His house is equipped with various sensors to monitor and analyze his activities of daily living (ADL). CASIS is deployed to provide personal reminders for health measurements, meals and medication. CASIS also enhances the elder's quality of life by managing his phone messages and information sources like TV programs or news. Even though Mr. Chang is living alone, he is not at all at risk in terms of getting medical assistance. CASIS issues timely alerts so help is only a few minutes away in case of emergency. His doctor, dietician, and concerned family members are well-informed of his status via web-based interface to CASIS services. In addition, grownup children living afar may monitor the elder's general activities, diet, and health condition anytime, anywhere via state-of-the-art mobile devices.

2.2 Goals

This research explores how technologies can help enhance the quality of care for elders living in a smart environment. The CASIS framework aims to support a happy, healthy and independent lifestyle by providing the following services.

1. *Smart furniture*: The elders can interact with a variety of intelligent interactive objects in a typical home environment. For example, we deploy the *Smart Floor* for non-intrusive location tracking, the *Smart Chair* for logging of vital signs, and the *Smart Table* for monitoring food consumption and nutritional intake.
2. *Context-Aware Information Services*: The elders may receive timely and personalized information services. Using an event-driven calendar, CASIS generates voice reminders, e.g. for taking medicine, when the elder is home, whereas it sends text reminders when the elder is outside of the house. The TV is turned on with his favorite program if the elder sits down on the sofa during specific times of the day. CASIS controls the operating mode of the telephone depending on the elder's wakefulness.
3. *Healthcare Services*: CASIS serves as the gateway for healthcare professionals to get updated and aggregated bio data on the elder's health conditions. The information enables the doctors to offer timely advice and/or prescriptions that can promote the long-term health of the elder.

3 A Multi-Agent Service Framework

Software architecture of CASIS will be given in this section, including overall introduction, and the detailed description of each important component.

3.1 System Architecture

A multi-agent platform deploys the context-aware and service oriented architecture on the heterogonous hardware, and integrates software components with the web service technologies. Every agent in this platform are loosely coupled and only has to concentrate on its main tasks. As a result, the CASIS supplies a smart environment that is capable of attending the elders by providing appropriate services (e.g. interactions, health-care activities, or reminders) in a non-intrusive way.

System architecture of CASIS is illustrated in Figure 1. There is a Context Event Broker to exchange the context information, a Context Repository to store context for later retrieving, and a Context Visualizer to query and to format context. Sensors or devices are connected and managed by Device Agents. Events generated by either Device Agents or Inference Agent will be sent to Context Event Broker by Web Services Adaptor. Context Event Broker and External Services Providers exchange messages for interacting with CASIS software agents. Context Event Broker will help deliver these event messages assuredly. Furthermore, external people evolving in the elder care can access context information according to their roles and responsibilities via web browser, and this action is managed by the Access Permission Control component.

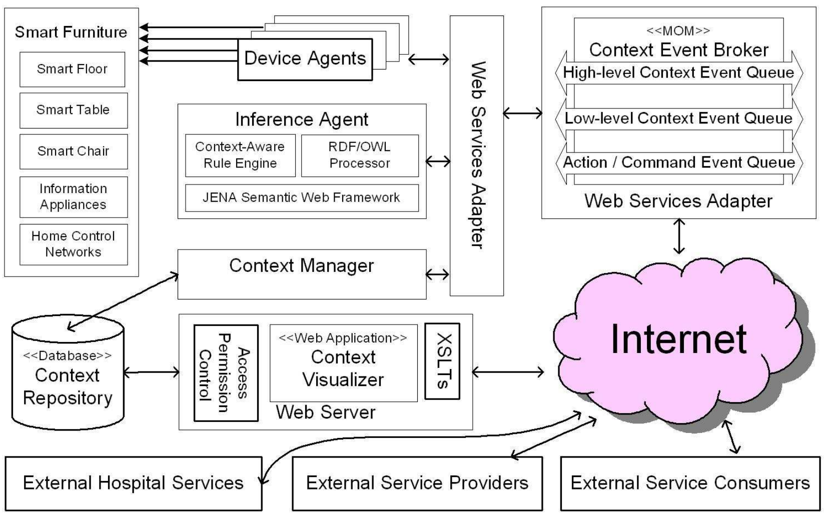

Fig. 1. CASIS system architecture

3.2 Component Description

Detailed description of each important components in Figure 1 will be elaborated in this section, and brief summary of these components is given in Table 1.

Context Event Broker The Context Event Broker is a message center with the publish-subscribe mode. In our design, there are three different event topics in the Context Event Broker: the *high-level context-event topic*, *low-level context-event topic*, and *action-event topic*. The purposes of the high-level context-event topic and low-level context-event topic are self-explaining. The Device Agents will subscribe the action-event topic, and issue control commands to the managed smart devices or facilities when receiving specific action events, detailed event flow model is depicted in Figure 2.

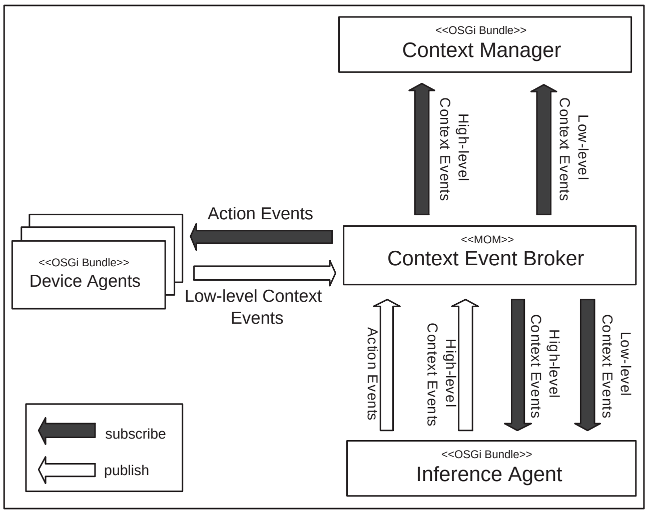

Fig. 2. Event flow model in CASIS

Device Agent In addition to gather raw sensing data and transform them into RDF/XML format before sending messages out, Device Agent also plays the role of device manager, which receives action commands from the Context Event Broker and issues these commands to devices by generating low-level device-dependent instructions.

Inference Agent Inference Agent is responsible for reasoning tasks. On receiving context events from Context Event Broker, the Inference Agent will perform inference tasks according to pre-defined rules and knowledge base. The outcomes of inference procedures are translated into action commands or treated as inferred high-level context then posted back to the high-level context event topic. Based on the inference results, agent may issue commands to devices by publishing events through action command topic or store the inferred higher-level context events into high-level context event topic.

Context Manager Context Manager will first subscribe events from Context Event Broker, then listen to subscribed context events. After receiving context events, it will store these event messages with timestamps into Context Repository for further use.

Web Services Adapter For the CASIS to integrate heterogeneous Agents, Components, Services, and Systems, Service Oriented Architecture is adopted. Via Web services Adapter, the heterogeneous components in the CASIS is packaged as Web Services, so these components can easily communicate with each other and interact with external services.

Context Visualizer and Access Permission Control Context Visualizer provides an interface for the authorized service providers, families, caregivers and system administrators to query or manipulate the observed contextual information of elders. It will translate the context data in the Context Repository and format these data according to the XSLTs. As for the Access Permission Control, it is a component to check if the current action for accessing context is legal. This component will authenticate the person accessing data via requiring his/her identity and password, and then compare his/her authority with the confidential level of the accessed context.

Table 1. Agents and services in CASIS

Name	Responsibilities
Device Agent	Communicate with smart appliances or devices through device dependent API or network sockets.
Inference Agent	Perform inference procedures triggered by the context events.
Context Manager	Provide the context event persistence services.
Context Visualizer	Provide the interface for users to access context.
Context Event Broker	Message Center to broker context messages.
Web Services Adaptor	Gateway for agents to exchange messages with external services.

4 Implementation

We have emloyed open-source software in the implementation of CASIS. The detailed software and hardware infrastructure will be described in this section.

4.1 Infrastructure

CASIS is designed to integrate a variety of home appliances and sensors. The smart facilities and devices deployed in the smart home are shown on the left hand side of Figure 3. Authorized users can retrieve information remotely via Internet-ready mobile devices. Inside the smart home, an OSGi-based Smart Home Gateway is responsible for managing the environment, and serving as a web portal for outside connections. Besides communicating to sensors for vital signs monitoring and identification, e.g. bio-sensors, pressure sensors and RFID readers, the gateway also manages a variety of smart devices, such as Smart Chair, Smart Table, and Smart Floor, etc. These smart furniture are computer-controlled, and can communicate with the home gateway via a local area network.

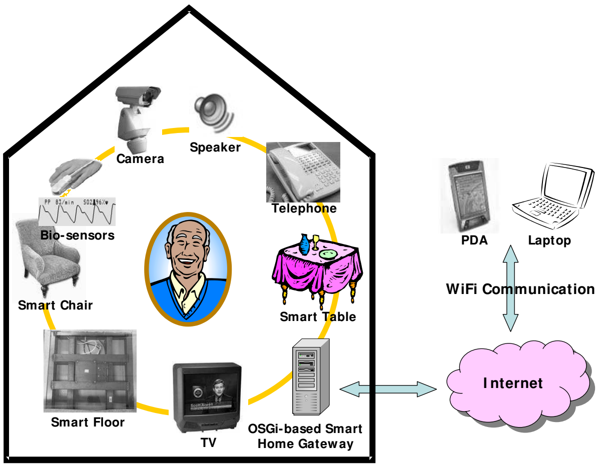

Fig. 3. Hardware infrastructure

4.2 CASIS

Table 2 lists the open-source Java tools that are used in the CASIS implementation. CASIS adopts SOAP as the agent communication protocol. Figure 4 shows two sam-

Table 2. The software requirements

System Function	Software or Application Framework
Context Event Broker	OpenJMS [2], SAAJ [3] and JAXM [4]
Inference Agent	Jess [5] and HP Jena Semantic Framework [6]
Context Manager	Hibernate Persistence Framework[7]

ple context events in RDF/XML format. The advantages of representing context in RDF/XML are two folds. First, each RDF triple has a direct mapping into a logical relation. Second, the RDF/XML syntax specification is a W3C recommendation, which is compatible with the semantic web and web service standards.

OSGi-based Smart Home Gateway The CASIS home gateway is a PC running the OSGi platform, which acts as a container for several cooperative agents and service

```
...
<context>
  <subject>Mr.Chang</subject>
  <predicate>activity</predicate>
  <object>sleeping</object>
</context>
...
<context>
  <subject>telephone</subject>
  <predicate>state</predicate>
  <object>auto-answer</object>
</context>
...
```

Fig. 4. Context in RDF/XML format

components. To deploy in the home gateway, the *Device Agent*, *Inference Agent*, *Context Manger*, and *Web Services Adapter* are packaged into OSGi bundles according to the OSGi specification[8]. The OSGi platform comes with a built-in service-oriented component model. Each service can lookup and then bind to other services dynamically with a central service registry.

Context Event Broker The Context Event Broker is essentially a message-oriented middleware (MOM) that dispatches and transforms the event messages from internal and external event sources. In general, there are two message-routing modes in MOM: *point to point* and *publish-subscribe*. The Context Event Broker in CASIS is configured with the publish-subscribe mode in which several named *topics* are predefined for publishing and subscribing. MOM clients are loosely coupled since they can bind (publish/subscribe) or unbind to a specific topic dynamically without interrupting the system's operation. The authorized external service providers can monitor the physiological context events with synchronized Web Services mechanisms such as SAAJ [3] and JAXM [4] to provide appropriate services to the inhabitants of the smart environment.

Inference Agent Context may change dynamically. For example, an elder's location and behavior change continuously as he moves around at home. A traditional software system with predefined procedures cannot respond to such changes. In most cases, it is both time and cost consuming to modify the control flow inside a software system. A context-aware system tries to provide users relevant and suitable services based on the sensed context. The question is "How does one determine what services should be provided given the current context?". One promising approach is to separate the logic or control from the program and represent them as rules, in simple if-then statements. A rule-based system allows developers to construct knowledge base consisting of rules and facts, and to deduce new facts using a rule engine. The advantage of the rule-based approach is its *flexibility* and *maintainability*. We have developed a context-aware rule engine (CARE) [9] based on Jess [5], a general-purpose rule engine written in java. CARE continuously updates the current context from sensors and performs context-aware reasoning using *dynamic rule loading*. As a result, CASIS is able to provide appropriate services at the right time based on the current situation. To handle messages in RDF/XML, the Inference Agent uses the RDF/OWL Processor and related ontology to create input context for CARE.

Context Visualizer and Access Permission Control CASIS provides XML-based query interfaces for the users, Context Visualizer utilizes XSLT (eXtensible Stylesheet Language Transformations) to transform the query results from XML into other appropriate documents. CASIS represents all information in XML. Every query is associated with an XSL template maintained by the Context Visualizer, which translates the query results into the right format. The Access Permission Control component maintains a list for all users, as well as their pre-defined access control types. In this work, access control is defined in terms of four different roles, which are Physician, Dietician, Family, and Normal.

Device Agent Device Agents are tightly coupled with the Smart Furniture, which will be described in Section 4.3.

4.3 Smart Furniture

In this subsection, several Smart Furniture we have implemented and used in this work are introduced.

Smart Table Due to hardware technology improvements, now we can deploy different kinds of sensors in the environment to collect rich contextual information. In recent years, RFID technology provides an easy and effective way to do identify multiple objects. By tagging cheap passive RFID tags on the targets, one can track hundreds of objects or persons in just few seconds. In our work, we have augmented a dining table with two layers of sensor surfaces underneath - the RFID surface and the weighing surface[10]. These sensor surfaces are divided into 3x3 sensor cells. Each sensor cell contains a RFID reader/antenna and a weighing sensor. The RFID surface serves two functions: (1) it enables identification of RFID-tagged tabletop objects, and (2) it tracks cell locations of these objects through their RFID tags. By combining the RFID and weighing surfaces, our system can trace the complete food movement path from its tabletop container source to other containers, and eventually to the individual. Thus, we can easily track what and how the elder eat, furthermore, we analyze their food consumption of each meal, such information can be stored in database and later accessed by other care members, like nutritionist and physician, to determine their health condition.

Smart Floor Many previous context-aware work[11–13] suggest *location* is one of the primary context types. Perhaps it is the most suitable source among the context because one's location doesn't need the explicit manual input, e.g. you use GPS to locate yourself at outdoors. In this work, for indoor location system, we use our prior work which utilizes the sensory block covered by wooden floor to track elders in a smart home[14]. There are 25 sensory blocks deployed in a common living room, and any pressure exerted on the sensory block will be represented as the change of voltage by the load sensor. The ADC (Analog to Digital Converter) will sense such voltage changes and then translate it to weight reading for server. After transforming, the system adopts probabilistic data association and LeZi-Update to analyze the collected data and estimate where the elder is. Our experiment shows that the error distance between the estimated location and the real location of a resident is less than 28.28 cm in 85 percent cases.

Smart Chair The ideal smart chair is a comfortable chair embedded with variety kinds of bio-sensors which can automatically detect the sitter's health status, and these data can be accessed by or delivered to the computers. So with the help of smart chair, the health status of the elder can be easily monitored when he/she sits at the smart chair. However, there is no such smart chair existing in the current market. Nevertheless, the bio-sensors, the comfortable chair, and the computers are all available, so we simulate the smart chair by arranging varieties of bio-sensors on the chair for the elder to use, and setting up a computer connecting to these bio-sensors to collect the detected health data. As for those bio-sensors which can not provide data to the computer directly, we implemented a web interface for the elders to input their health data after measuring their own health status.

4.4 Context-Aware Information Services

In this subsection, we will introduce two services implemented and used in this work.

Intelligent Telephone In order not to disturb the elder, when he/she is sleeping, the telephone should not give a phone ring. Figure 5 shows that such task is achieved by several cooperative agents that activated on OSGi platform. The device agent of smart camera continuously monitor the activity of the resident, when a sleeping activity is recognized, the agent will send a event containing related context information to the high-level context topic to declare the resident's state is sleeping. Such context events will be captured by Inference Agent which subscribes to this topic. After the Inference Agent finds that the telephone should switch to "leave-message" mode by referring to its knowledge base and pre-defined rules, it decides send an action command to the action command topic. The Device Agent which manages the smart telephone then receives this mode switching command, thus switches the telephone's mode from "ring" to "leave-message". When a new incoming call arrives, the smart telephone will redirect the call to leave message instead of giving a phone ring to disturb the elder.

Intelligent Reminder The services of Intelligent Reminder are deployed by the event publish/subscribe approach of the Context Event Broker, the reminding messages events have been subscribed beforehand, and will be delivered on a "convenient" device based

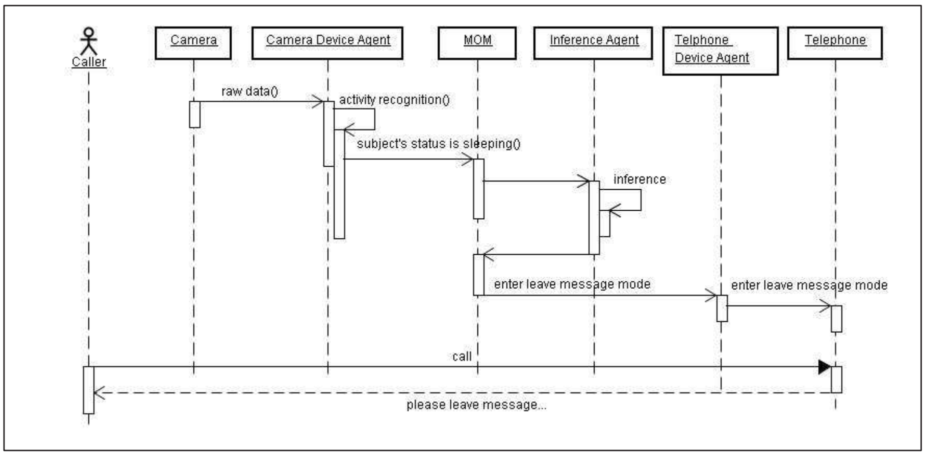

Fig. 5. Agent interactions of Intelligent Telephone control application

on the location context of the elder. In this work, the reminding events are scheduled by the Physician or Dietitian to remind the elder to take medicine or measure his/her own health status. When one of the events happens, the Inference Agent will first reason about where the elder's current location is, and then decide the appropriate way to remind the elder. If the elder is at home, the more specific and effective way will be adopted, e.g. playing voice message via the speaker. Otherwise, the easier way will be adopted, e.g. playing sound and sending text message to the mobile device the elder carried.

5 Demonstration

Detailed description and sample screenshots of the scenario will be presented in this section. In order to validate our platform, we design a prototype utilizes agent technologies to integrate services and fulfill the elders' needs. As Section 2.1 mentions that Mr. Change lives in a smart house, for reminding him to take his medication on time, CASIS should send the message to the right device; Figure 6(a) shows a text message has been sent to the PDA that Mr. Chang has carried when he is outside of house. Figure 7 displays the sensors data of Smart Chair, which collects Mr. Chang's vital signs when he is sitting on the it. Mr. Chang always eat meals at a Smart Table, it can detect how much and what kind of food that Mr. Chang has consumed. The dietician will regularly take these food consumption factors into consideration and designs meal plan (Figure 6(b)) for Mr. Chang. Caregivers and extended family members can remotely check the elder's health status via a web-based interface, shows as in Figure 6(c).

(a) Text Reminder (b) Meal Menu (c) Health Fact Sheet

Fig. 6. Context-aware and Healthcare Services

6 Related Work

While the demand for in-home healthcare for the aging population is relatively new, research and development for critical enabling technologies have been gaining tremendous momentum in recent years.

Pollack[15] surveys AI technologies that can support elders who are grappling with cognitive decline. Assistive technology can help elder to perform necessary daily activities safely, or send an alert to caregivers. Activity monitoring and assurance systems provide alarms and status reports while compensation systems assist elder to accomplish their daily activities. Environment navigation systems aim to guide people can easily find their way, these system are deployed on modern location tracking technologies, *e.g.* GPS, bluetooth and RFID. The AI planning techniques enhance the flexibility of management systems, temporal reasoning generates reminder plans satisfied the time constraints of users. Sensor-based monitoring can provide continual assessment of elder's cognitive status.

House_n project from MIT[16] shows an example of proactive (or preventive) healthcare system using wearable biometric sensors and cameras to detect symptoms of congestive heart failures (CHF) which occur frequently in elders over age of 65. When symptoms, such as abnormal changes in weight, blood pressure, sleep patterns, etc., are detected, a proactive healthcare system can generate health alerts and recommend remedial changes in lifestyles (e.g., moderate level of exercises) to prevent CHF. LiveNet system from MIT[17] is a mobile wearable platform consisted of various biometric sensors and a communication radio that can stream bio-signals to the remote caregivers.

SHARP (a System for Human Activity Recognition and Prediction) system at Intel Research and University of Washington[18] is working on enabling a "widely applicable activity inference" system. The system attaches thousands of passive RFID tags to everyday objects throughout the elder's home (e.g., teapots, faucet, stove, etc.). The project then asks an elder to wear a glove that contains a small RFID reader that can

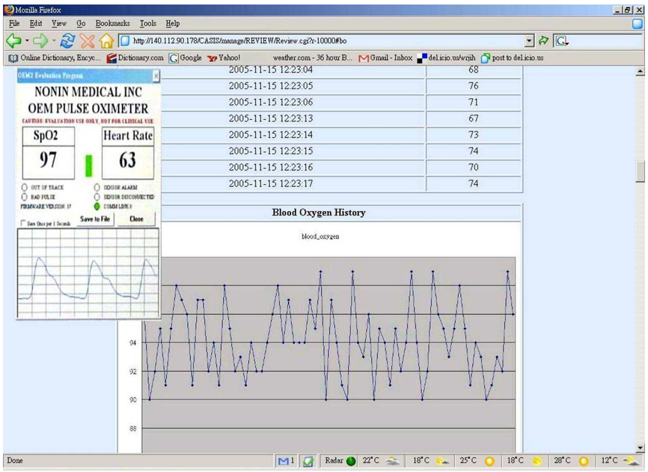

Fig. 7. Sensor Data and Vital Signs

read off RFIDs of objects the elder touches. Based on the sequence of touched objects, the inference engine can interpret daily activities of the elder. CareMedia project at CMU[19] uses camera and image processing to understand, track and assess the healthy behavior of dementia elders in nursing home. It aims to create a meaningful, manageable information resource that enables more complete and accurate assessment, diagnosis, treatment, and evaluation of behavioral problems for the elderly. Through activity and environmental monitoring in a skilled nursing facility, a continuous, voluminous audio and video record is captured. Through work in information extraction, behavior analysis and synthesis, this record is transformed into an information asset whose efficient, secure presentation empowers geriatric care specialists with greater insights into problems, effectiveness of treatments, and determination of environmental and social influences on patient behavior.

The Everyday Computing Lab at Georgia Institute of Technology introduces the *digital family portrait* (DFP) [20, 21] to provide surrogate social support for aging people who is living alone. A *living laboratory* with multi-discipline sensors has been constructed for monitoring the activities of the resident, the sensor data is used to create a digital frame, which is presented to the elder's family lives in a remote house. The DFP is designed to be hung on the wall, but it changes daily, reflecting a portion of the elder's life. This can provide the distant family members day-to-day awareness information of their senior parent, and can promote the peace of mind for young family members who stay far away from home. Similar to the DFP, researchers at Intel have developed CareNet [22] addresses the needs of the Care Network, such network represents the care-giving relationship among elder, family and caregivers.

7 Conclusion and Future Work

This paper presented CASIS, a prototype system designed to facilitate independent living of the elderly. The system provides a variety of services for the elder, as well as related services for family, friends, healthcare professionals, and external service providers. Connecting all caring services together in a service-oriented framework, CASIS coordinates them to provide personalized services. The service-oriented architecture supports loosely coupled system components to cooperate through clearly defined communication interface. The OSGi platform and event-driven middleware provide a robust communication platform at the bottom level, so that application developers may build applications on top of the platform to achieve service cooperation via event publishing and subscribing.

The current implementation deals with sample elderly care scenarios in order to demonstrate all CASIS functionalities. The system needs to be further enhanced by exploring more complex cases. For example, CASIS should be able to handle conflicting data from multiple different sensors. It can also benefit from defining more activity models, *etc.* As CASIS is a multi-agent system, we will follow some agent standards (*e.g.* FIPA) or migrate our system to a mult-agent platform (*e.g.* JADE).

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