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Ubiquitous supervisory system based on social contexts using ontology

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Abstract. As described in this paper, we propose a supervisory system that considers actual situations and social aspects of users in a ubiquitous computing environment. To realize gentle and safe supervision while providing efficient supervisory services, the system must recognize the situations of a watched person, such as the person's physical condition. To achieve this, we have proposed a ubiquitous supervisory system "uEyes", which introduces Social Context Awareness: a distinguishing feature for supervision. Using this feature, the system can combine environmental information acquired from sensors in the real world and common-sense knowledge related to human activities in daily life. As described in this paper, we specifically examine design of Social Context Awareness using ontology technologies. Based on this advanced feature, a live video streaming system is configured autonomously depending on the users' circumstances in runtime. We implemented a uEyes prototype for supervising elderly people and performed some experiments based on several scenarios. Based on those experimental results, we confirmed that the social contexts are handled effectively to support the supervision.

Keywords: Supervisory system, Social Context Awareness, ontology, temporal concept

1. Introduction

Real-time multimedia supervisory systems are widely used as care-support systems that can be applied to supervision of children and elderly people from remote sites connected by wide-area networks. Studies are at the initial stage to deploy this system to the ubiquitous computing environment [13,15,23]. Some studies have investigated delivery of video streaming from a selected camera that is physically close to the target person using positional information of the target [5,18]. Furthermore, some studies have developed flexible displays that play video seamlessly from the nearest display device to the observer based on the watcher's location [16,32].

The contribution of these studies is to increase the usability of the system. However, when some emergency situation such as the condition of the watched person's health worsens, or when a person wants to protect their own privacy, the system is expected to cope with these situations while supervising autonomously with no user interaction. In previous works, the location information of a user is used only for specifying the user's physical location. A more sophisticated mechanism is needed to infer the circumstances and requirements of users from analyses of their location information.

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To achieve gentle and safe supervision, the actual situation of and around the watched person should be judged using limited sensing data available from the real world. We must also cope with social relationships between observers and the watched person, such as family relationships or friendships, to assign an adequate privacy level to the services. To realize this, we have proposed a ubiquitous supervisory system – “uEyes” – that overcomes the issues described above.

We introduce Social Context Awareness [29,30] into uEyes. Here the Social Context Awareness is a distinguishing feature for the watching; it is a capability of the system that can recognize the actual situation of users and social relationship between users using common-sense knowledge of social aspects. We build uEyes based on the concept of Symbiotic Computing [21,28,31] to achieve the points described above. We design the features by effectively combining environmental information acquired from the real world with knowledge related to social activities of people. Knowledge related to social contexts such as human relationships, general behavior of elderly persons, the lifestyle of the watched person, and structure of the house, are introduced and used effectively to deduce the user’s circumstances. This feature enhances the social awareness of the system: the resultant system is gentle and safe for users.

In a prior work [30], we proposed the conceptual design of the Social Context Awareness. Subsequently, we explained its detailed design of using ontology technology. We also demonstrated the comprehensive effects with the Social Context Awareness, as well as other components in uEyes, in [29]. As described in this paper, we extend the Social Context Awareness to enable handling of various real situations by enhancing the ontology technologies. Actually, we introduce concepts to represent temporal facts into the ontology that can describe repetitive behaviors of people in daily life.

We implemented a prototype of uEyes involving the extended ontologies and performed some experiments based on several real-life scenarios. For instance, we assumed a scenario in which an elderly person is watched by his family and neighbors of the local community. We confirmed that when the elderly person was in his bedroom, a live video streaming system with low quality was configured to protect his privacy. During an emergency, the system lowered the privacy level and autonomously informed the local community’s members of the situation with high-quality video information. We also confirmed that, through extension of Social Context Awareness, uEyes can recognize unusual activities and notify related members of the situation. For example, when the elderly person is sleeping in a bedroom at midnight and he sleeps between 23:00 and 5:00 every day, his privacy is protected. However, when he is sleeping at lunchtime, uEyes recognizes it as an unusual situation, e.g., he might be in bed with a cold. Other members are therefore informed of the situation. From the results of these case studies, we confirmed that uEyes can provide real-time multimedia watching service for elderly people, with reasonable QoS and privacy according to each user’s situation.

2. Related work

Several research groups are working to apply real-time multimedia supervisory system to ubiquitous computing environments. In some studies, the systems deliver video streaming from the nearest camera to the target people based on physical position information of the target [5,18]. The other research direction emphasizes flexible display technologies that seamlessly play video streaming from the nearest display to the watching person according to location information [16,32]. Techniques of this kind are sometimes called “service migration”.

These studies include functions to select existing cameras and displays based on a user’s location information. They contribute to provisioning of care-support services anytime and anywhere. However, from viewpoints of contexts of the actual situation of the supervision, these studies present some limitations. For instance, when a tag is recognized to be located in a low position, these systems cannot judge some situations: is the watched person sleeping in the bedroom as usual, or lying down in an emergency situation? Fundamentally, these systems judge the situation of the watched person solely according to the user's location information. For this kind of situation, deep analysis should directly affect the supervision itself. For example, in the case of an emergency, live video streaming of reasonable video quality should be sent to as many watchers as possible. In contrast, when the watched person is sleeping, video information should be sent with emphasis on privacy concerns.

To solve these problems, a system must recognize and incorporate the context of various entities involving the users in ubiquitous computing environments. Therefore, knowledge representation techniques are necessary to introduce knowledge into the system and to process information about various situations of the entities. As one technique, some studies use an ontology for knowledge representation [4,7,20, 29,30].

In prior studies, we investigated a 'watch-over' system introducing "Social Context Awareness [29, 30]." Here, the ontology is used to express the knowledge about watching over someone. Task Computing [20] fills the gap separating those tasks to be done by the user from the services that offer feasible functions to the user. Using ontology, Task Computing can find services in the environment dynamically and construct them into user tasks along with other services on the users' devices and remote environments. GAS Ontology [4] provides a common language for communication and collaboration among the heterogeneous devices that constitute these environments. This ontology also supports the service discovery mechanism that a ubiquitous computing environment requires. Harry et al. describe an ontology for supporting pervasive context-aware systems [7]. This ontology is a collection of ontologies for describing places, agents and events and their associated properties in an intelligent meeting-room domain. They also develop an agent architecture that provides knowledge sharing, context reasoning and privacy protection support for pervasive context-aware systems by using the ontology.

However, these ontologies in the previous studies are limited to express temporal concepts. The temporal concepts are important for ubiquitous computing environments to represent social knowledge.

From this viewpoint, some studies reported in the relevant literature introduce temporal concepts into the ontology [2,3,11,26]. In prior studies [2,3], the authors attach time labeling to a triple in RDF and define that the triple is valid only for the interval noted in the time labeling. In [11,26], knowledge about time is expressed using the ontology. For example, this ontology represents a time interval, its anteroposterior and coincidental relations: a calendar and a clock.

Furthermore, Chen et al. define Standard Ontology for Ubiquitous and Pervasive Applications (SOUPA) [6] by which they attempt to incorporate temporal concepts to ontology in a ubiquitous and pervasive application domain. This ontology includes modular component vocabularies to represent intelligent agents with associated beliefs, desires, intentions, time, space, events, user profiles, actions, and policies for security and privacy. They discuss the context-aware smart meeting application based on the ontology. Using these ontologies, we can express relations between timelines of human behaviors; we can also represent when a person takes some action. However, we cannot express repetitive behaviors of people such as "the person eats a meal at 18 every day." Ubiquitous computing environments are linked closely to the daily life of people. Therefore, using temporal concepts, we must represent knowledge about repetitive behaviors that express the lifestyle of people using the ontology.

3. Overview of uEyes

Figure 1 depicts our target supervision task. In this figure, community members such as the target person's family and neighbors cooperatively watch over the target person. We designate such a watching

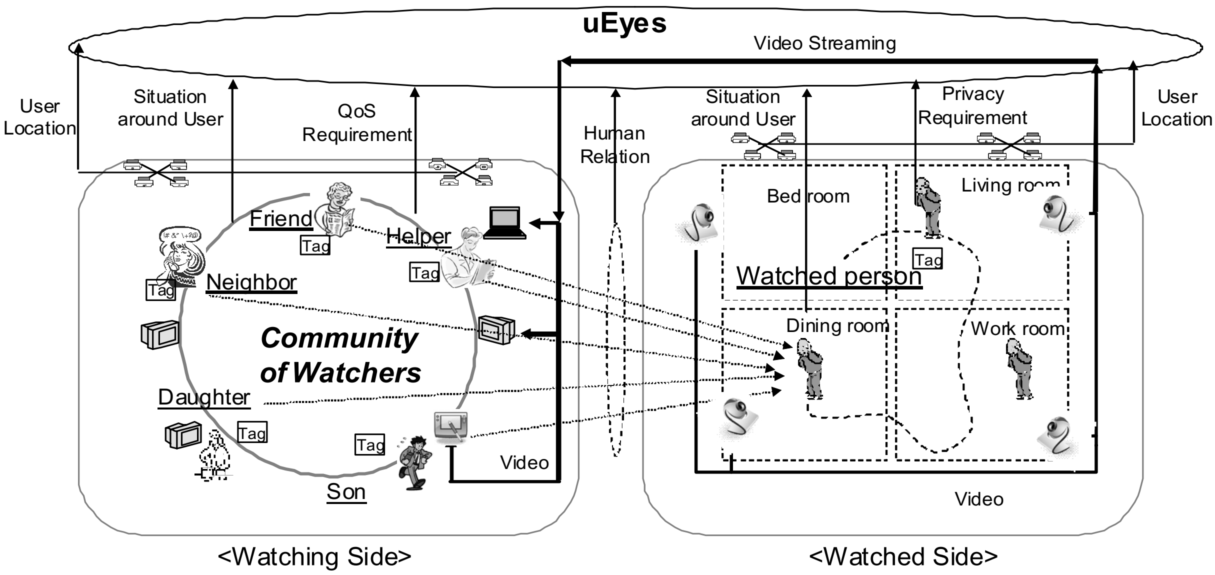

Fig. 1. Concept of uEyes.

task as a "Community-based supervisory task." uEyes aims at solving the problem described in Section 2 in this supervisory task. To achieve this, it is necessary to introduce mechanisms by which an entire system configuration consisting of various system elements is selected and organized dynamically according to the states of the system, users, situation around the users and social aspects.

To realize this, we newly introduce awarenesses of the following three types.

(S1) Device Context Awareness: uEyes copes with and coordinates various contexts of ubiquitous devices for providing appropriate QoS of watching systems. The contexts include statuses of the display and camera devices, available resources of PCs and hand-held devices, and available network access and bandwidth, in addition to user location.

(S2) User Context Awareness: uEyes closely associates with users' requirements for watching tasks in the best possible way. For example, when a watcher wants to view the facial color of the watched person vividly using video streaming, a high-quality, magnified image should also appear in the nearest display.

(S3) Social Context Awareness: uEyes deeply considers social relationships between the watched person and watchers, and protects a desired level of privacy according to the situation. For instance, in a normal situation, the watched person's privacy should be protected, however during emergencies, the privacy level would be lowered moderately.

Because we discussed (S1) and (S2) in previous reports [8,9,12] , we omit their details here. In [30], we proposed the basic concept of (S3). In [29], we concentrated on the detailed design and implementation of (S3) Social Context Awareness of uEyes. As described in this paper, we explain an extension of (S3) Social Context Awareness.

Figure 2 portrays a functional model of uEyes. Device Context Awareness comprises a set of components for a video streaming system and sensor devices for capturing raw data from the real world. User Context Awareness plays a role in capturing a user's behavior, in addition to the related conditions and context. Social Context Awareness is used for recognizing social relationships between the watched

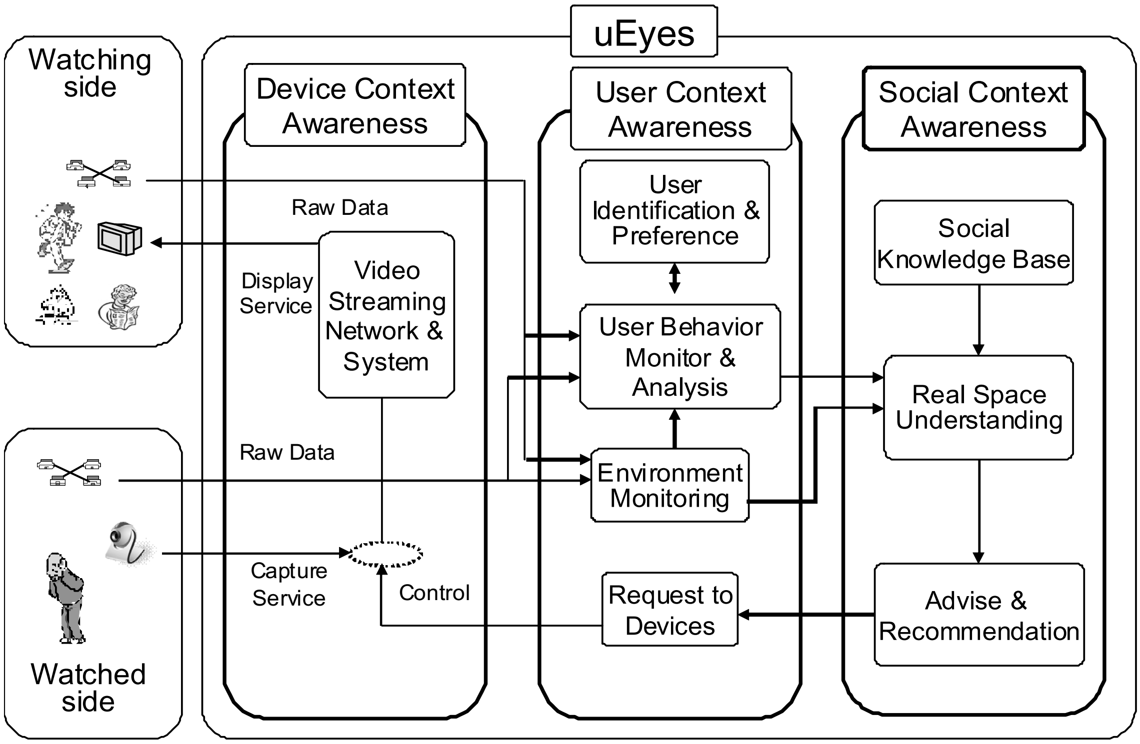

Fig. 2. Functional model of uEyes.

and watching person. It understands the user's current presence and situation. Each of the three mechanisms has functional modules, as portrayed in Fig. 2; these modules work cooperatively to support the supervisory task described in the previous section.

4. Mechanism for Social Context Awareness

4.1. Real space understanding mechanism

To realize a safe and convenient supervisory system, we need a mechanism for recognizing each user's actual requirements from the "situation of users" and "human relationships", with no burden to system operation. We wish to use many kinds of sensing data for obtaining users' situations, but available sensing data are limited by installation conditions. Moreover, regarding human relationships, users do not want to exhibit all of their personal information: they seek to protect their privacy. Therefore, it is difficult to judge the situations and relationships of users precisely using limited information from real space. We take the approach of improving the social context awareness of our system to overcome this problem. We introduce "Social Knowledge" to infer a user's situation and their human relationships. We introduce a method to create a quality/privacy request to the video streaming system based on the recognized results.

We propose a "Real Space Understanding Mechanism" to infer the situation and relationship of users by combining sensing information and Social Knowledge. The sensing information is data about the environment that are acquired from real space. Such information includes a user's physical location and

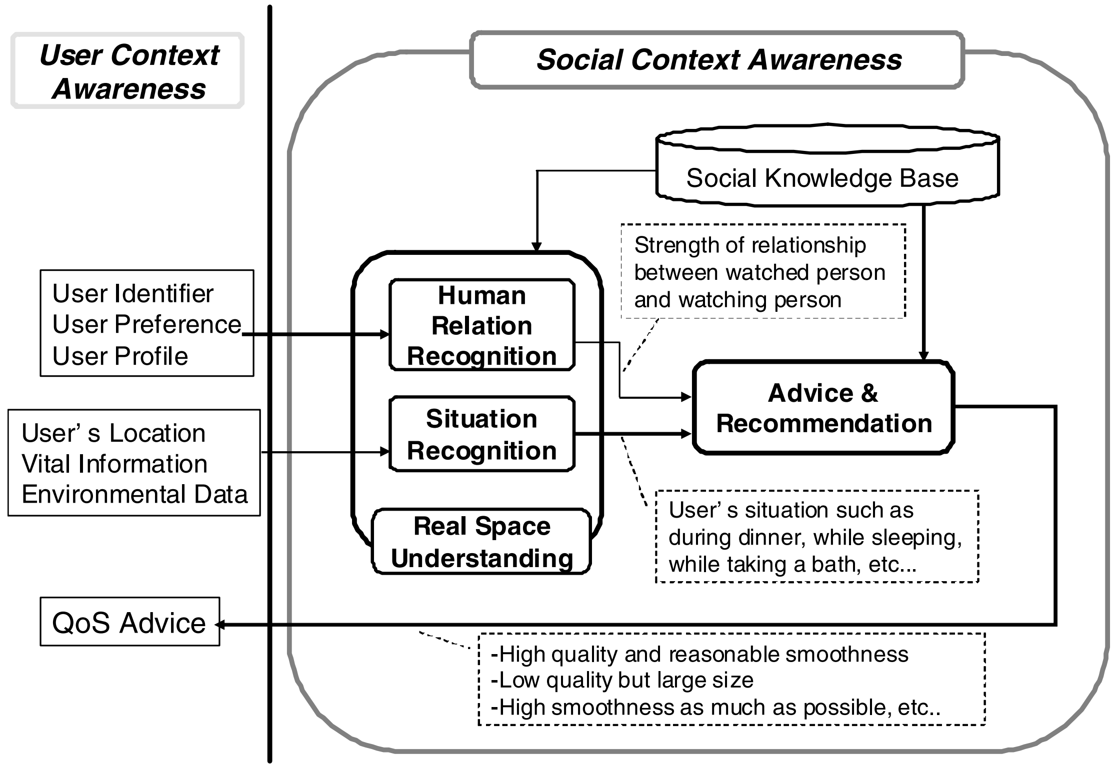

Fig. 3. Relationships among mechanisms in Social Context Awareness.

its change over time. Social Knowledge involves common-sense knowledge related to human relations, human behavior, human lifestyle, structure of the living space, etc. Figure 3 presents a structure of the Real Space Understanding Mechanism. This mechanism has two functions addressing "Human Relation Recognition" and "Situation Recognition". Human Relation Recognition derives the strength of relationship between watched person and the watching person according to a user's identifier, preference, profile, etc. Situation Recognition deduces the user's situation such as "during dinner", "while sleeping", and "while taking a bath" based on real-world data such as the user's location and environmental data.

The recognized information is sent to an "Advice & Recommendation" mechanism, which produces user-oriented QoS requirements for video streaming system based on the recognized results. For example, when the user requirement for high-quality video is derived in a situation where the watcher is worried about the watched person's health condition, the mechanism creates a request for high quality in video encoding. It issues a request to degrade the quality of the video when user requirements demand a high level of privacy. Moreover, in case of an emergency affecting the watched person, it produces a request for reasonable quality of video that is delivered to as many watchers as possible.

We employ ontology as a knowledge description scheme to represent Social Knowledge and environmental information. The ontology can incorporate the conceptual entity of the target domain and the relationship among the entities. We use the context ontology defined in [27]. The context ontology expresses knowledge for ubiquitous computing and consists of the Person, Location, Activity, and Computational Entity. Each concept has relations that might be similar to those shown in Fig. 4. In our system, we define the properties, subclasses, and individuals (instances) to each basic concept, particularly addressing the supervisory system domain.

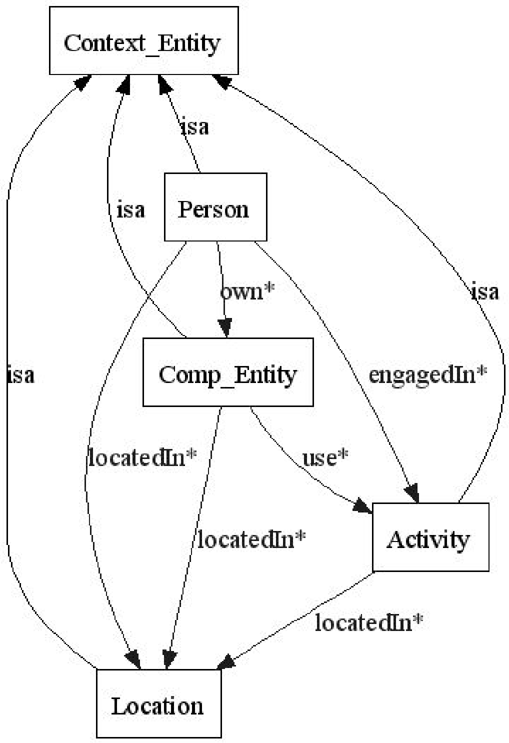

Fig. 4. Core context ontology for uEyes.

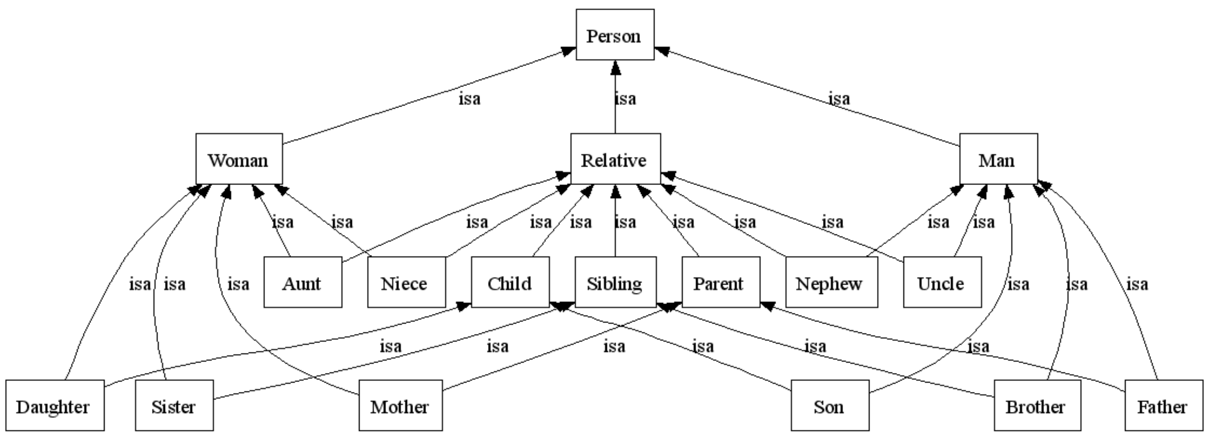

Fig. 5. Human relationship ontology.

4.2. Human Relation Recognition function

The Human Relation Recognition function derives a human relationship between the watching person and the watched person, such as a family relation, a friendship, and a block association relation. Human relationship ontology is introduced into our system to conduct and express these relations. Figure 5 shows the class hierarchy of the human relationship ontology. Here the "Person" in Fig. 5 has some relations such

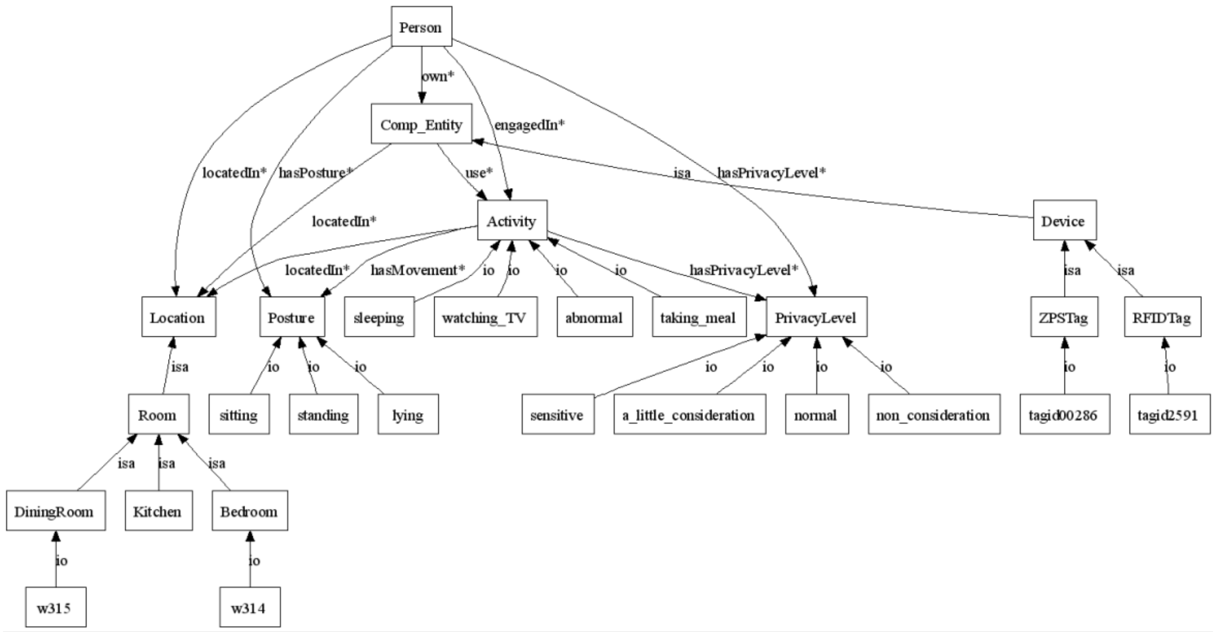

Fig. 6. Ontology to represent the circumstances of users.

as "hasChild", "hasParent", "hasSon", "hasRelative", "hasTownResident", and "hasVicinityResident".

The family relation can be derived from each user's information about gender, partners, and children. All blood relations can be complemented from those three pieces of information, using ontology and the rules [1]. The block association relation can be acquired from an address given to each user. For example, the following two rules can derive the "hasSon" relation and "hasTownResident" relation:

Man(?user2) $\wedge$ hasChild(?user1, ?user2)
$\rightarrow$ hasSon(?user1, ?user2)
hasAddress(?user1, ?address1) $\wedge$ hasPlaceName(?address1, ?placeName) $\wedge$ hasAddress(?user2, ?address2) $\wedge$ hasPlaceName(?address2, ?placeName)
$\rightarrow$ hasTownResident(?user1, ?user2)

Combining the ontology and rules, this system can complement the missing human relation information automatically. In the current version of this function, only the direct friendship is given statically. However, it would be obtained dynamically through socialization in local community activities.

4.3. Situation recognition function

The Situation Recognition function infers the situation of the watched person by combining sensing data about the real space such as the user's location and social knowledge. Figure 6 portrays a part of ontology used in the Situation Recognition function. We added some necessary entities for the supervision domain to the four basic elements of the context ontology described in Section 4.1. This ontology expresses a semantic relationship between concepts of devices, location, life space, human activities, persons, etc., related to the supervisory task. Applying this ontology and rules, this system recognizes the actual situation of users from the acquired sensing data. For example, the following rule

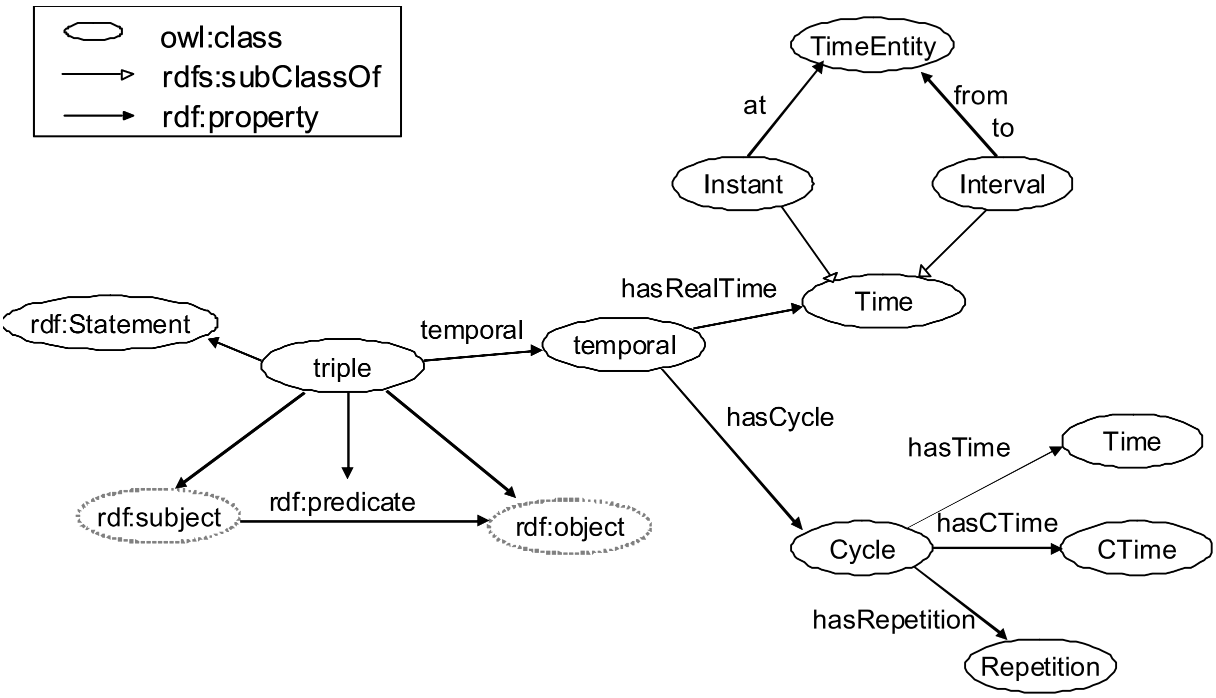

Fig. 7. Temporal ontology.

is knowledge to recognize the user's location. This rule means that "if a user has a tag, and the tag is put on a room, then the user is located in the room".

owns(?user, ?tag) $\wedge$ putOn(?tag, ?room)
$\rightarrow$ locatedIn(?user, ?room)

4.4. Ontology for temporal concept

Furthermore, we introduce temporal concepts to represent the user's repetitive behaviors. This extension provides powerful description capability to the basic ontology by introducing temporal concepts of human activities. Especially, we can represent lifestyle habits of the user using the ontology with temporal concepts. Figure 7 shows our temporal concepts to represent repetitive behaviors of the user. Using the ontology presented in Fig. 6, the user's activities are expressed as rdf:subject, rdf:predicate, and rdf:object (triple). We can add temporal information to the triple using the "temporal" property. The temporal class has two properties: "hasRealTime" and "hasCycle," which respectively express the current time when the user is doing the specific activity, and how often the user does the activity. This representation enables explicit description of the user's lifestyle habits. An Instant means a certain point of time (e.g., year-month-day and clock time), and Interval means an extent of time (e.g., from one day to another day and for a certain number of hours). TimeEntity is a class that expresses time. It can express the date and time, e.g., "May 25, 2008" and "10:20." The concepts of Instant, Interval, and TimeEntity are similar to those presented in [2,3,6,11,26]. Moreover, we introduce the "Cycle" class to express a period of time. This is intended to represent repetitive behaviors of the user. Cycle has "Time", "CTime", and "Repetition" classes. Time represents the time during which the user usually does an

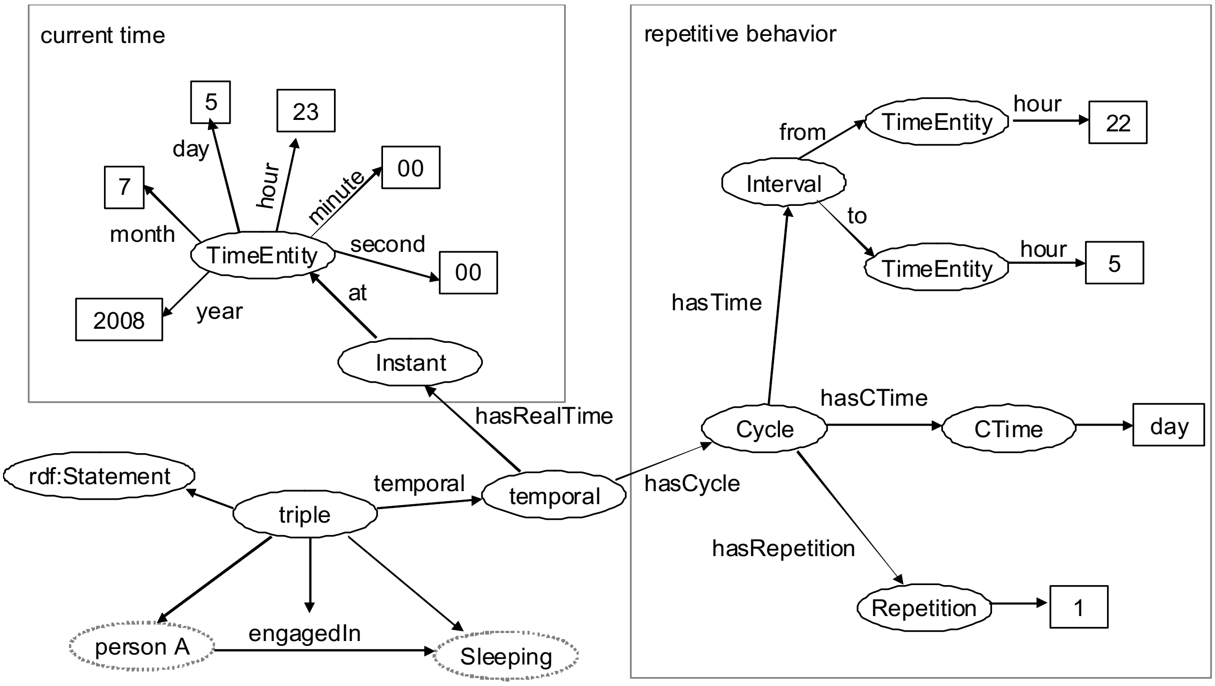

Fig. 8. Ontology to represent repeated behaviors of users.

activity. Repetition shows how often the user does the activity as a positive integer. CTime means a unit of repetition.

Figure 8 shows an example of representing repetitive behavior, i.e., the lifestyle habit of the user. This example presents that "person A is sleeping at 23:00 on July 5, 2008, and person A sleeps between 22:00 and 5:00 every day."

4.5. Behavior of functions based on temporal ontology

Here we explain the behavior of our system. Figure 9 presents an example of behavior. Presume that a rule described in the top-left text box is executed. It has four conditions. If all conditions are satisfied, the rule is executed. Then, the circumstances in which elderly person A is sleeping are inferred. Similarly, from a rule shown in the middle-left text box, the situation "the height up to the chest of the elderly person A will be around 100 mm high, and it will remain in the same position more than 180 s" is conducted.

In some cases, conflict will arise between inference results. This conflict is an important point to judge whether the situation is normal or not. Therefore, the system autonomously recognizes a situation that does not conform to the usual status. This policy is natural for such problem solving because it is impractical to describe all abnormal situations that might occur in the real world. We present unusual situations by drawing inferences from finite knowledge of common sense.

In the case of Fig. 9, this inferred situation has a conflict with the situation expressed in the top-right text box. This is acquired from environmental information. It says that the tag with ID $= 2$ is actually remaining in the same position for 300 s. Therefore, a conflict does not exist in terms of the height and temporary movement of the tag.

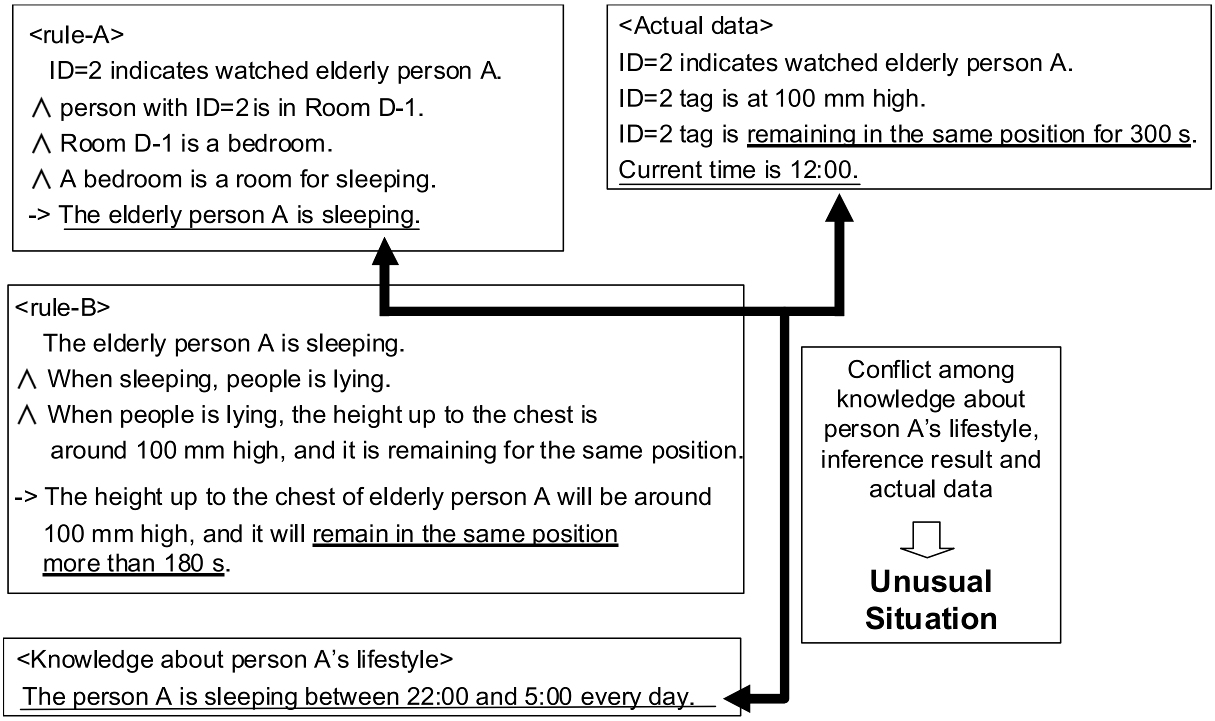

Fig. 9. Example of behavior of the Real Space Understanding Mechanism.

However, using temporal concepts introduced to ontology to represent repetitive behaviors, the knowledge of person A's lifestyle, "Person A is sleeping between 22:00 and 5:00 every day" is added. In this case, a conflict occurs between the inference result based on the knowledge and the actual data. Thereby, this function recognizes that some unusual situation might have occurred.

5. Application: Supervisory system for elderly people

5.1. Implementation

We are developing an application of uEyes to supervise elderly people at home. We use some USB cameras for capturing live video of the watched person. For watchers, PC displays are used to play the live video. Live streaming is realized by application of the Java Media Framework [25]. To obtain location information of users in the rooms, we use sensor systems: Furukawa's Zone Positioning System (ZPS) [33] for ultrasonic sensors, and an active RFID system produced by Fujitsu Software Technologies Ltd [14].

For the implementation, we use DASH, a multiagent-based programming environment based on the ADIPS Framework [24]. Each agent in ADIPS has its own knowledge base and inference engine. We describe ontology using Web Ontology Language (OWL) [19] and rule in Semantic Web Rule Language (SWRL) [22]. Then we convert them to a Java Expert System Shell (Jess) format [10]. This conversion is necessary because of performance concerns.

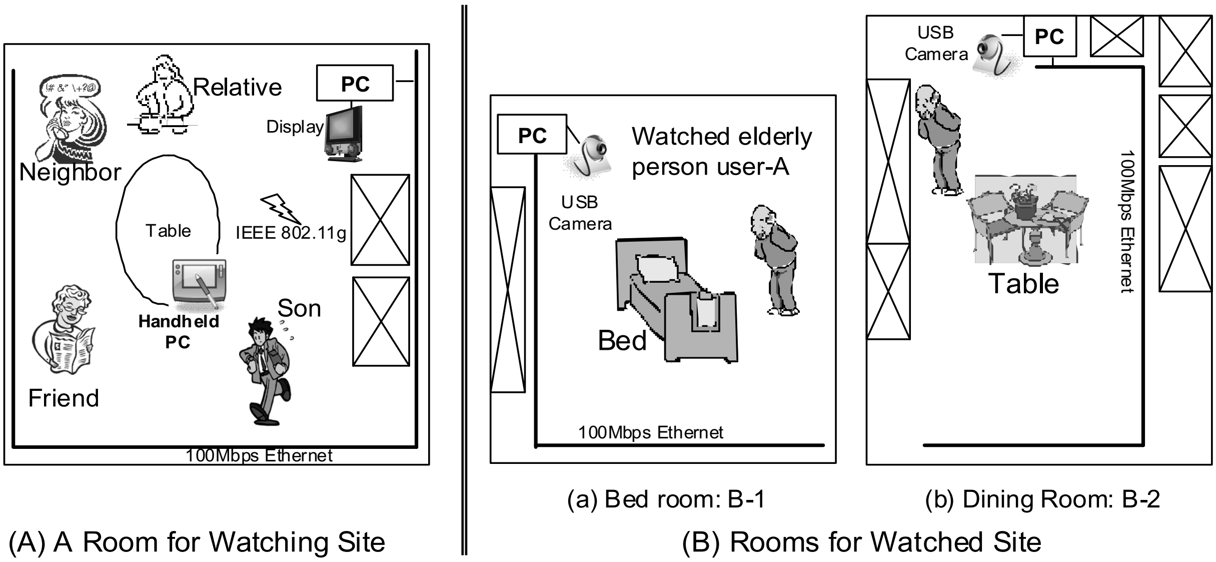

Fig. 10. Experimental room settings.

5.2. Knowledge representation

We present an example of subclass description. It is represented as "(`deftemplate Man extends Person`)" in Jess [17] when describing the "Man" class as a subclass of "Person" class. As an example of an individual (instance) of a class, when "room-A" is represented as an instance of the "LivingRoom" class, it is expressed as "(`assert (LivingRoom (name room-A))`)" in Jess.

Here is an example of rule description in SWRL. This rule shows "if a user has a tag, if the tag is at 100 mm high from the floor, and if it is staying for 60 s, then the user is lying down on the floor".

owns(?user, ?tag) ∧ hasHeight(?tag, ?height)
∧ swrlb:lessThan(?height, 100) ∧ stayFor(?tag, ?duration)
∧ swrlb:greaterThan(?duration, 60) → hasMovement(?user, Lying)

However in Jess syntax, it is implemented as follows:

```
(defrule Def-userMovement (owns ?user ?tag) (hasHeight ?tag ?height)
(test (< ?height 100)) (stayFor ?tag ?duration) (test (> ?duration 60))
⇒ (assert (hasMovement ?user Lying))).
```

6. Experiments and evaluation

6.1. Experimental environment

In application scenarios to evaluate the feasibility and effectiveness of our system, we assume a situation in which the elderly person is supervised by four people sharing some relation with the person: his son, a relative, a neighbor and a friend living nearby, e.g. on the same block. Figure 10(A) portrays a room used as a watching site. In this watching site, the RFID system is used to obtain the location of the watcher. Figure 10(B) presents the setting of the rooms for the watched site. We set two experimental rooms in the watched site: a bedroom and a dining room. A ZPS ultrasonic sensor is used in the watched rooms as a location sensor.

Here, presume that the elderly person who is watched is designated as "user-A" is in the bedroom (B-1) or in the dining room (B-2). In this situation, our system will select the most appropriate camera and PC display with a reasonable network connection in these rooms. Then, a suitable quality of live streaming video is captured and displayed to a PC on the watching side.

We perform three experiments. The first experiment (Exp. 1) evaluates the effectiveness of the Real Space Understanding Mechanism. The second experiment (Exp. 2) confirms the effect of Social Context Awareness in uEyes. The third experiment (Exp. 3) is to evaluate the performance of Social Context Awareness.

6.2. Exp. 1: Effect of Real Space Understanding mechanism

In Exp. 1, we evaluate the effect of "Real Space Understanding" mechanism by itself. We perform the experiment using virtual test data of real space and confirming the output of the inference result to verify the behavior and effectiveness of the proposed mechanism. We present four patterns of test data, considering the actual situation of an elderly watched person. The given data consist of a tag ID, a room ID where the tag is located, the height of the tag from floor, the staying duration, and the current time.

First, we assume that the watched person, user-A, is sleeping in the bedroom at night. We give the following data as an input of the mechanism: Tag-ID, Tag1; Tag-Position, B-1; Tag-height, 100 mm; Staying-duration, 300 s; Current-time, 23:00 (Exp. 1(1)). The result is presented in Fig. 11. Without this mechanism, the given data would pass through to the output as they are. Therefore, the recognized results should read as "A tag with ID #1 is in the room B-1 at 23:00 and it is staying at 100 mm high for 300 s." On the other hand, using our mechanism, the output result is "Elderly person user-A is sleeping in the bedroom as usual." To recognize this situation, the following knowledge is mainly used:

– The watched person, user-A, has a tag: Tag1.
– If a Tag is at less than 200 mm height, and is staying in the same position for more than 60 s, the person is lying down.
– Room B-1 is a bedroom.
– A bedroom is a room for sleeping.
– A person who is sleeping is lying down.
– User-A sleeps between 22:00 and 5:00 every day.

This result demonstrates that Social Knowledge such as common sense of human behavior and house structure is used to create meaning on the environmental information obtained from real space. In this scenario, no conflict existed between the two inference results for posture of the persons, between environmental information and Social Knowledge. Both indicated that user-A is lying down. Additionally, no conflict occurred between the current time when user-A was doing the specific activity and the time when user-A usually does the activity. These facts engender the final judgement.

Next, we assume an emergency situation in which the elderly person is lying down in the dining room. We give the following data as an input of the function: Tag-ID, Tag1; Tag-Position, B-2; Tag-height, 100 mm; Staying-duration, 300 s; Current time, 12:30. The result of the experiment (Exp. 1(2)) is presented in Fig. 12.

We were able to obtain the inference result of "The elderly person, who is user-A is lying down in the dining room and is in an emergency situation." In addition to the knowledge used in Exp. 1(1), the following Social Knowledge is used in our actual experiment.

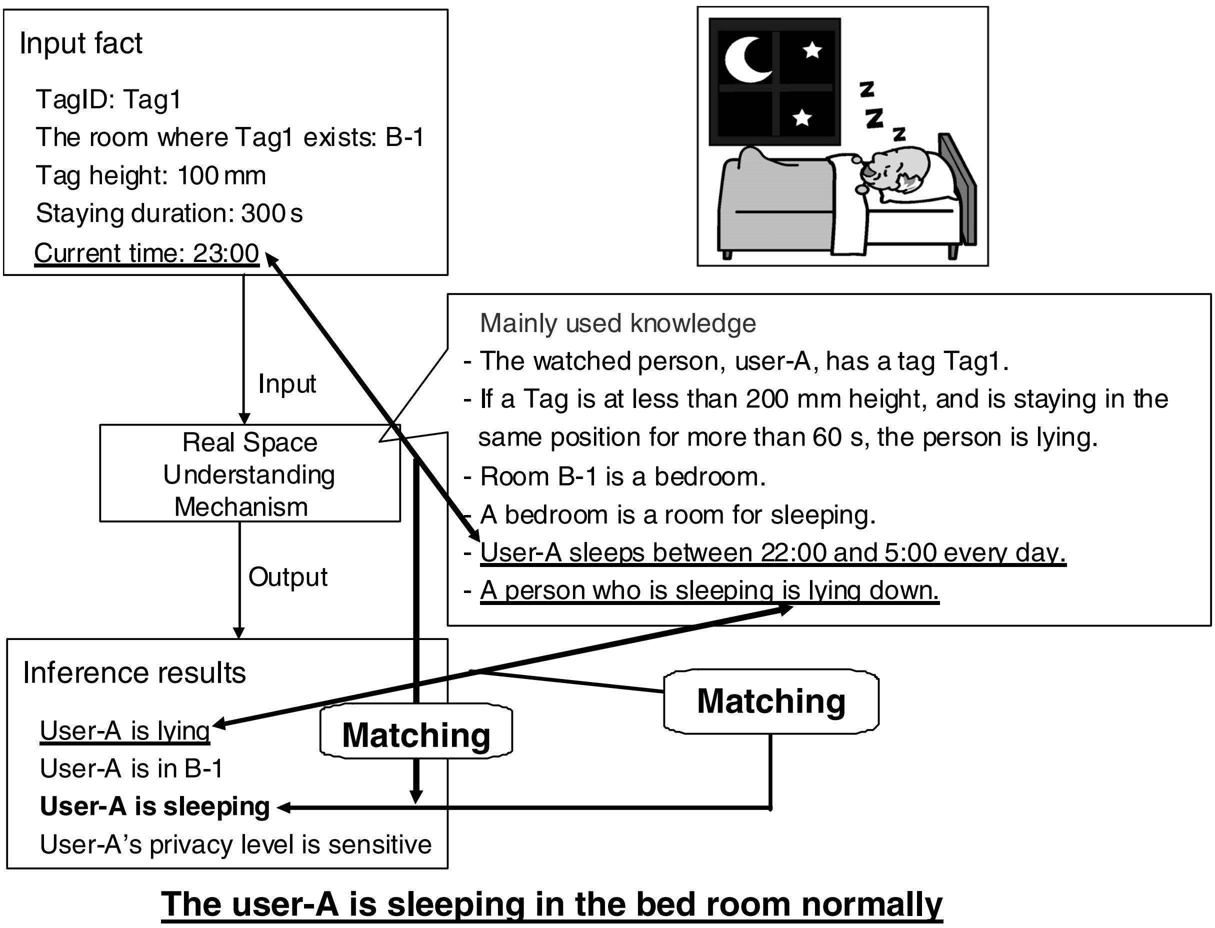

Fig. 11. Experiment result of Exp. 1(1): A normal situation (the user is sleeping).

– Room B-2 is a dining room.
– The dining room is a room for taking meals or doing activities.
– User-A eats lunch between 12:00 and 13:00 every day.
– When a person is doing some activity, he is standing.
– When a person is taking meals, she is sitting.

The room in this pattern differs from that in Exp. 1(1). Therefore, the presumed activity of the elderly person is also different. From the five Social Knowledge points described above, the function induces the result of "he is sitting down." However, the tag location from real space indicates that he is lying down. This represents an example of conflict. As a result, the function concluded that "he is in an emergency situation." The knowledge described in the middle right text box in Fig. 12 is mainly used to recognize this situation.

We assume that the elderly person is taking a meal in the dining room as usual (Exp. 1(3)). We give data with the same values as Exp. 1(2), except the tag height. In this case, the tag height is 1100 mm. Using our mechanism, the recognition result "Elderly person user-A is taking a meal in the dining room." was obtained. For this experiment, almost all Social Knowledge used in the previous experiment was used. However, conflict between the two inference results on the posture of the person was not detected.

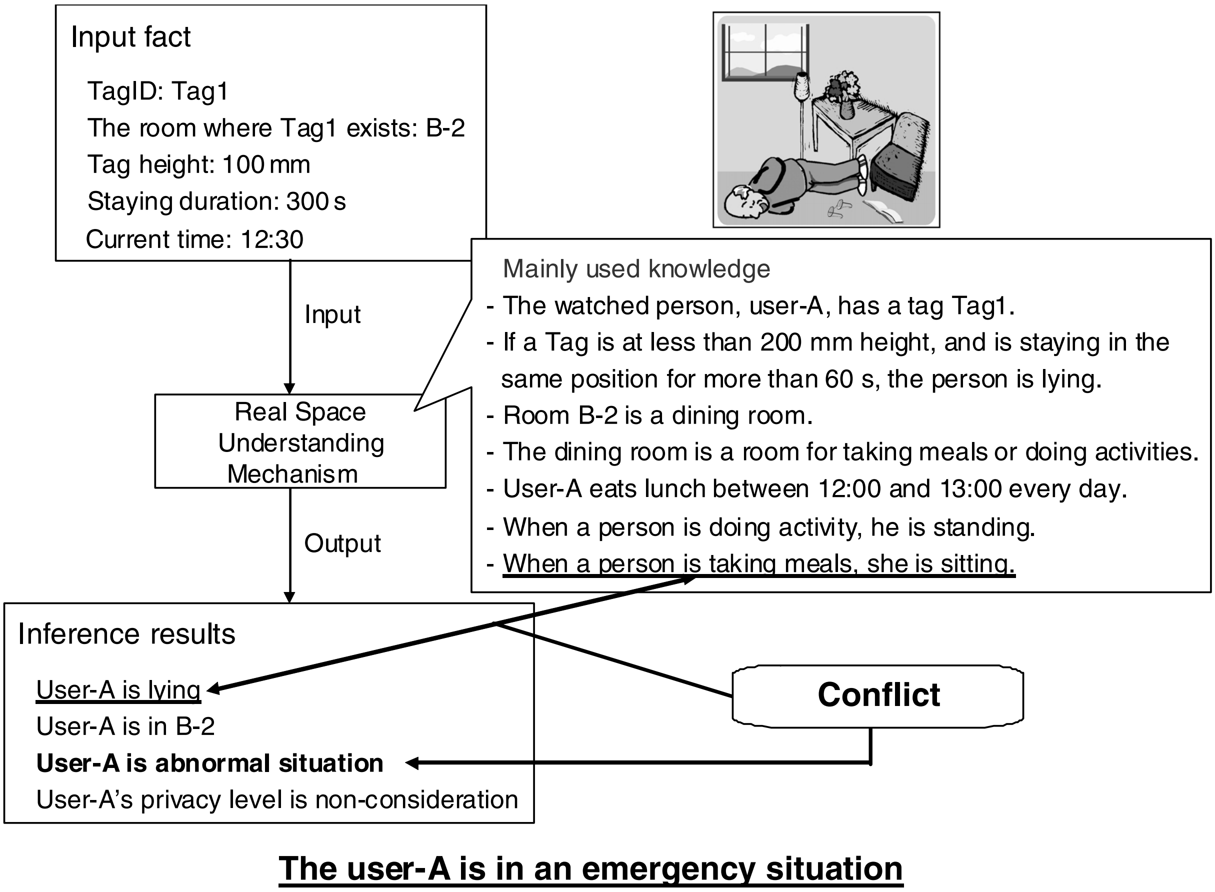

Fig. 12. Experiment result of Exp. 1(2): Emergency situation.

In addition, conflict between the current time and the user's lifestyle was not derived. Therefore, the result – "The action is normal" is inferred.

Finally, we assume that the elderly person is doing an unusual activity in the dining room (Exp. 1(4)). We give the following data as an input of the function: Tag-ID, Tag1; Tag-Position, B-2; Tag-height, 1300 mm; Staying duration, 5 s; Current time, 23:00. The result of the experiment (Exp. 1(4)) is shown in Fig. 14. Using our mechanism, the recognition result "Elderly person user-A is doing some activities, but his state is unusual." was obtained. In this experiment, almost all the Social Knowledge used in the previous experiment was used, and conflict in two inference results on posture of the person was not detected. However, conflict in two inference results on activity's time of the person was detected. Consequently, the result – "The action is unusual" is inferred.

6.3. Exp. 2: Effects of Social Context Awareness on uEyes

Subsequently, we have performed experiments to verify effects of Social Context Awareness on uEyes. It is expected that it can achieve and manage supervision by a community of two or more people because understanding of interpersonal relationships and recognition of the situation can be done using Social Context Awareness.

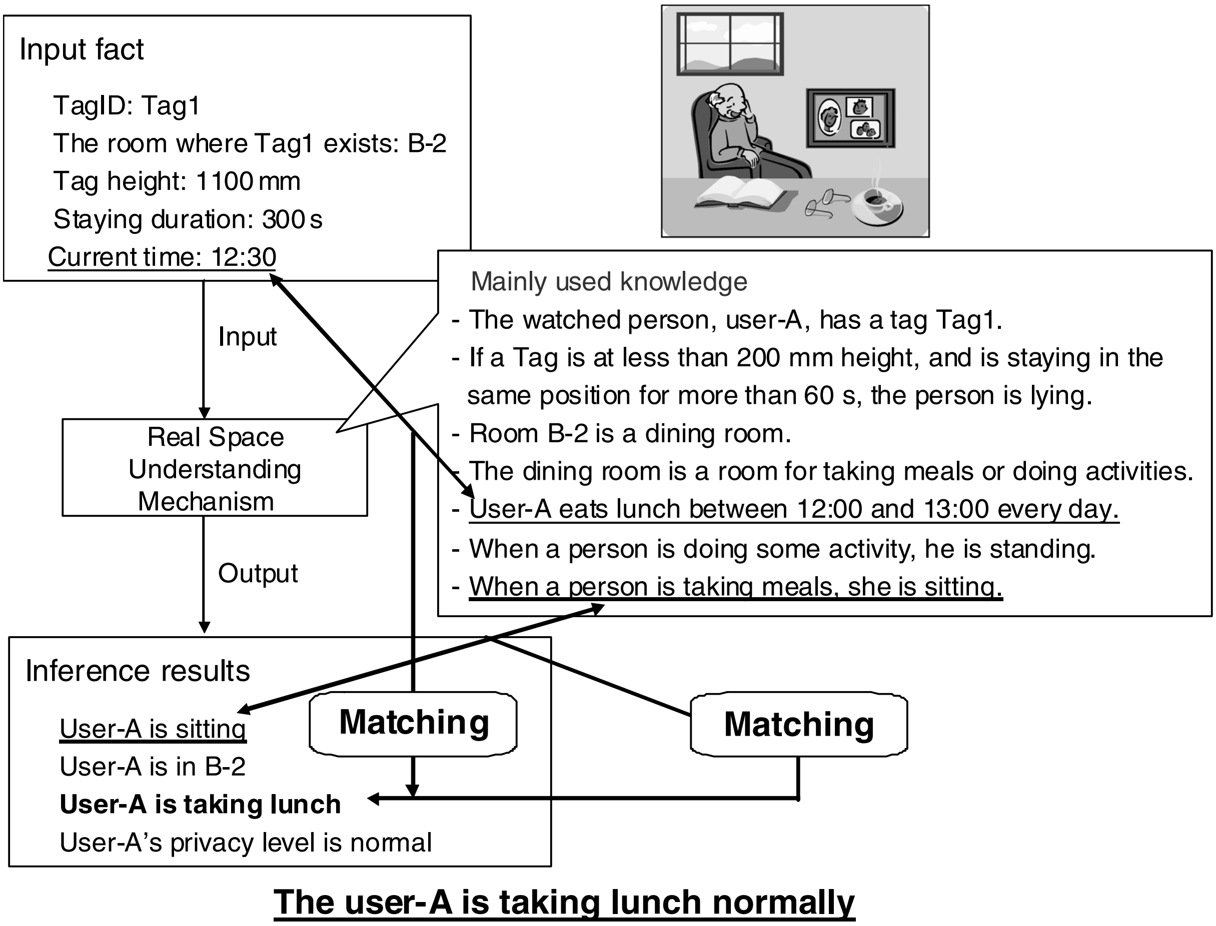

Fig. 13. Experiment result of Exp. 1(3): A normal situation (the user is taking lunch).

Here, we present an example of supervision by (a) the watched person's son, (b) a relative, (c) a neighbor with whom the watched person has a good relation, and (d) a person living in his same block. In a situation in which the watched person is doing activities, for example, he is in the dining room, each display from (a)–(d) is as shown in Fig. 15. In fact, Fig. 15(A) shows cases in which the watched person's privacy is protected because the state is normal. In this case, high-quality video is delivered to the son. The image of lower quality, which shows only movements, is delivered to the relative. The others do not receive the video because privacy concerns affect the delivery. Instead, they receive a picture image and text message that clarify the circumstances of the watched side. On the other hand, Fig. 15(B) shows the case in which the watching person is doing activities in the dining room at 23:00. The "Situation Recognition" function judges it as an unusual state based on the watched person's location, current time, and Social Knowledge. Therefore, the privacy level is lowered slightly. The son can watch the video with high quality, but the relative and the neighbor receive a low-quality video that shows only the appearance of the situation. A person living on the same block receives picture image and text message that announces that the watched person's state is unusual.

In our previous work, whenever the watched person is not lying down in the dining room (the watched person is sitting or standing in the dining room), the system recognizes the person is taking some activities

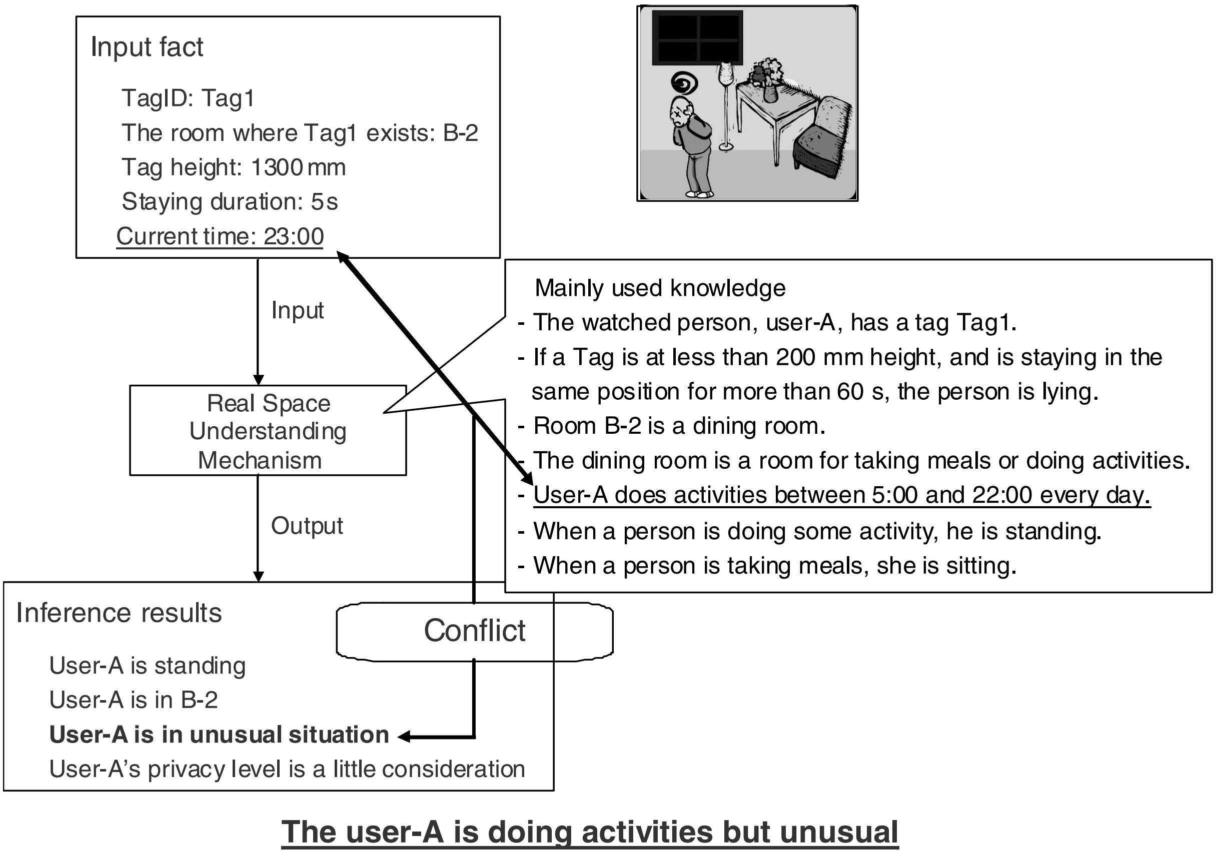

Fig. 14. Experiment result of Exp. 1(4): An unusual situation.

usually and can not detect an unusual situation. However, by introducing temporal concepts into our Social Awareness, our system can detect an unusual situation that is similar to that depicted in Fig. 15 considering the person's lifestyle habits.

Figure 16 depicts an example of the display in the emergency situation when the watched person collapses onto the floor. The "Situation Recognition" function judges it as a state of emergency such as falling down, using an elderly person's location information obtained from real space, and "Social Knowledge" related to the house structure. The display is changed so that many people can know the situation by lowering the privacy level. Concretely, an untouched video image is delivered to the son and the relative. The neighbor with a good relation receives a low-quality video; a person residing on the same block is notified by emergency message with a picture image.

The system can judge the emergency correctly in both cases (Fig. 16(A) and (B)) using temporal concepts in addition to the relation of ontology related to activity and location. The reason was that the watched person never lies down on the floor in the dining room, except in an emergency situation.

Figure 17 presents the displays when the watched person is sleeping in the bedroom. Figure 17(A) depicts the situation in which the watched person is sleeping, but is unusual because of a conflict between the current time he is sleeping and his lifestyle habits. The "Situation Recognition" function judges it as an unusual state, e.g., he might be in bed with a cold. Therefore, the privacy level is lowered slightly. The son can watch the video with high quality, and the relative and the neighbor receive a low-quality video.

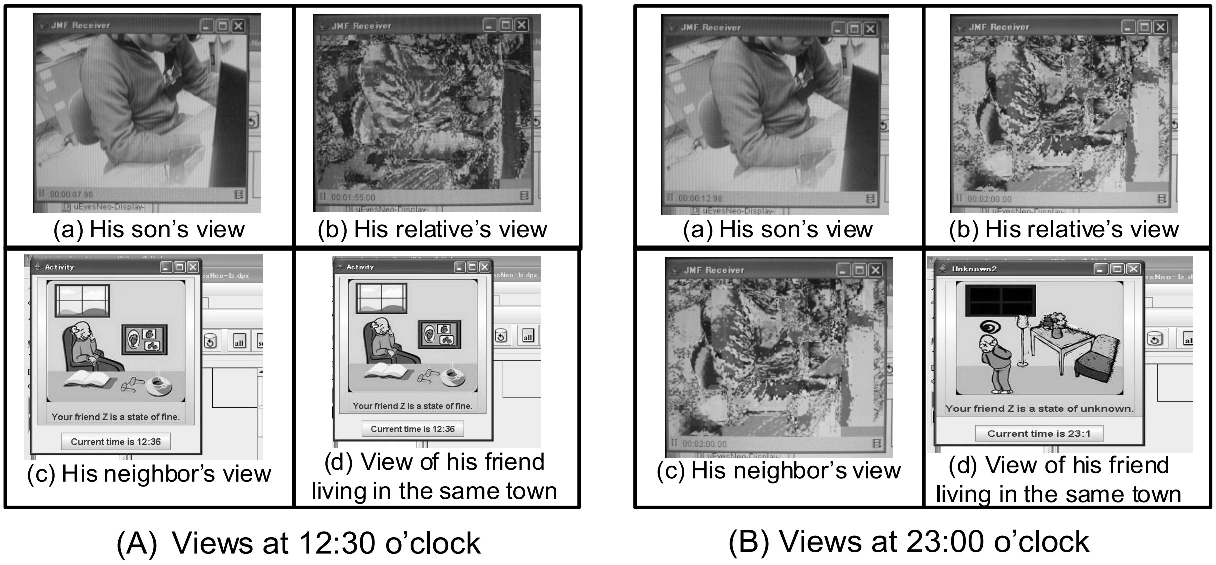

Fig. 15. Result of Exp. 2(1): Effect of Social Context Awareness in case that the watched person is doing an activity in the dining room.

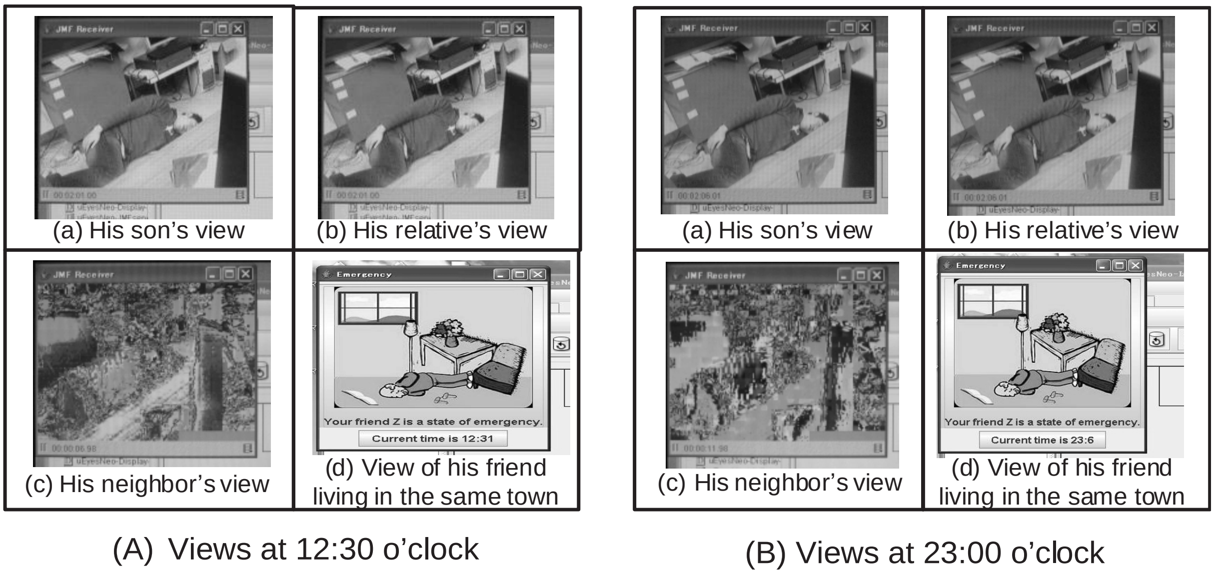

Fig. 16. Result of Exp. 2(2): Effect of Social Context Awareness in the case of watching a person in an emergency.

A person who lives on the same block receives a picture image and text message that announces that the watched person's state is unusual. The situation in which the watched person is sleeping normally at night is portrayed in Fig. 17(B). The "Situation Recognition" function judges it as a normal situation and protects his privacy. The son and the relative receive a low-quality video stream; the others receive a picture image and text message that he is sleeping.

In our previous work, whenever the watched person lies on the bed, the system recognizes that the person is sleeping usually and can not detect an unusual situation such as that the person might be in

Table 1
Numerical properties of the proposed system

Class	Property	Instance	Rule	Inference time
45	40	141	35	0.65 s

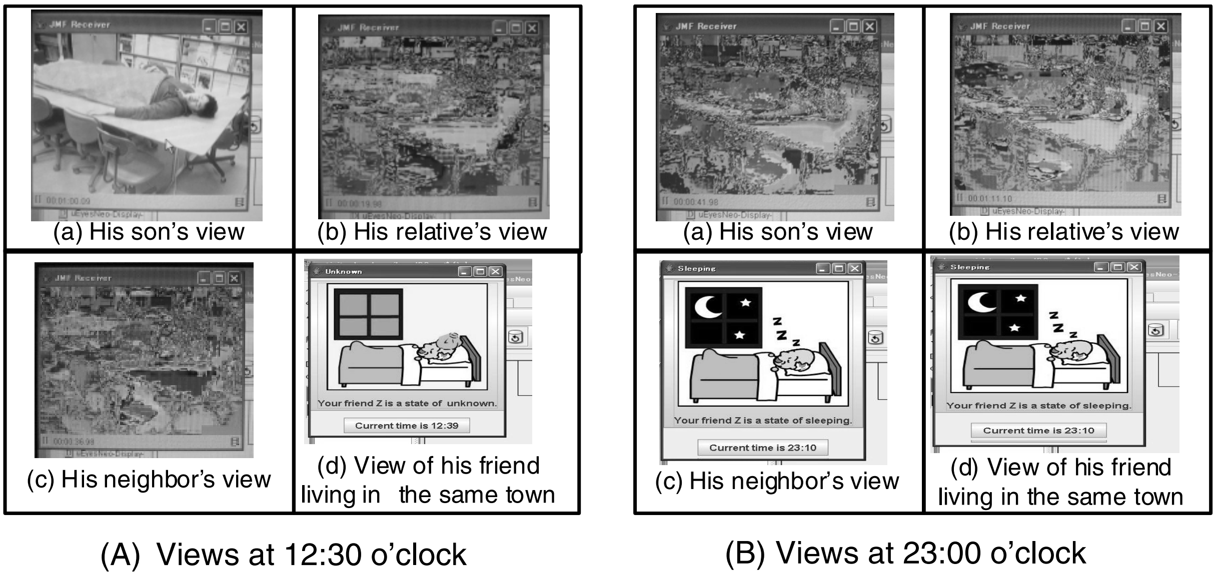

Fig. 17. Result of Exp. 2(3): Effect of Social Context Awareness in the case in which the watched person is sleeping in the bedroom.

bed with a cold. However, by extension of Social Context Awareness, our system can detect an unusual situation like that portrayed in Fig. 17.

As described above, we confirmed the advancement of the Social Context Awareness by the effects of temporal concepts.

6.4. Exp. 3: Performance of Social Context Awareness

We performed an experiment to measure the inference time for performance analysis of Social Context Awareness in uEyes. Actually, we observed the inference time in Jess time for deriving the watched person's state and his privacy level using the experiments described in Section 6.3 (Exp. 2). Table 1 reports the numerical property of our system: number of classes, properties, and instances, number of rules, and Jess's inference time. The current version of the ontology comprises a total of 45 classes, 40 properties, and 141 instances. We also defined 35 rules. The inference time was 0.65 s, on average. This result reflects that it is within an acceptable range for practical use.

6.5. Evaluation

6.5.1. Effect of real space understanding mechanism

We confirmed the effectiveness of our proposal through experiments described in previous sections. The results show that we can create meaningful information from raw data got from real space by introducing Social Knowledge. Therefore, our system can infer more types of situations than a system that recognizes situations solely from analyses of environmental data.

More general knowledge, including that of common sense, can be used not only in the supervisory application domain, but also in other domains. That is, by accumulating and managing general knowledge, the design and implementation of other types of application system based on Social Knowledge can be supported. In addition, by increasing the general knowledge, the situation dependent knowledge can be expected to be reduced, which would contribute greatly to increasing the development efficiency by decreasing the burden of knowledge description, which is a bottleneck of such systems.

6.5.2. Effect of employing ontology

Ontology serves an important role in this system to give, explicitly, the conceptual knowledge that represents the background of the real world. Using the ontology, this system can cope with situations that are not described explicitly, by referring to the conceptual relation among classes and instances. Compared to a method by which all possible situations are described exhaustively and in full detail, an ontology can handle a much wider range of situations with less knowledge description. Moreover, because ontology is standardized, the reuse of Social Knowledge would be accelerated.

6.5.3. Effect of Social Context Awareness in uEyes:

We confirmed the effect of Social Context Awareness from experiments in previous sections. Using this awareness, uEyes can recognize relationships among people in the real world and the detailed situation of the watched person. Based on that information, uEyes can handle the implicit requirements on QoS parameter and privacy level autonomously at an adequate level. An important feature of this system is its automatic acquisition of user requirements. It would be very difficult for elderly people to manipulate the system properly. Moreover, in an emergency situation, the watched person might be incapable of doing anything. This feature of automated operation would enable secure and safe supervisory services to be provided especially to non-expert users.

6.5.4. New inference mechanism for ubiquitous applications

This system integrates environmental information and Social Knowledge through application of a hybrid inference mechanism based on DASH and Jess. These two mechanisms' roles are different in the inference. Environmental information should be handled and analyzed in real-time; therefore, the lightweight processing capability of DASH is used effectively. On the other hand, the knowledge representation capability of Jess is superior to that of DASH. By integrating the two inference mechanisms, the gap of processing granularity between sensing data of the real world and social knowledge can be bridged. This inference mechanism will contribute to advanced ubiquitous applications.

6.5.5. Effect of introducing temporal concepts

We confirmed the effect of temporal concepts for Social Context Awareness from the results of experiments. A ubiquitous application is closely related to human daily life. Therefore, temporal concepts of Social Context Awareness are an important role that must be served for use in a ubiquitous computing environment. In this case, uEyes can recognize the actual situation considering the lifestyle habits of the watched person based on a temporal context. By introducing temporal concepts, the system enables adequate expression of the user's repetitive behaviors. This aspect engenders an improvement of existing Social Context Awareness.

7. Conclusion

In this report, we proposed a gentle system for supervision for ubiquitous care-support services. In this system, the situation of users and environmental information around users are handled effectively to provide supervisory services. Social Context Awareness such as that of human relationships is also considered to increase the sense of safety that is provided through supervision. We built an application of a supervisory system that is presumed to be provided for elderly people at home. We confirmed the effectiveness of the idea through some initial experiments using the prototype system.

In future work, we will continue to perform case studies addressing many different situations using this prototype system. We are also trying to extend the ontology and develop a method to infer a person's lifestyle habits. Furthermore, we are planning to measure the user's satisfaction in a quantitative manner. Moreover, we have a plan to carry out field tests to investigate the effects and issues of our system deeply in practical use.

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