An Extensible Situation-Aware Caring System for Real-World Smart Wards

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Abstract. Context-aware caring system is capable of effectively improving quality of health care in hospitals. Most of current context-aware health care systems adopt only simple context information, which only provide limited supports to caregivers. In this paper, we present the design and evaluation of a new situation-aware caring system for smart wards, which combines multiple contexts and infer patients' "situations". This system is built and evaluated in a real-world hospital. We also report lessons learned, preliminary results of empirical deployment, and questionnaire surveys of caregivers.

Keywords: Smart Ward, Context-awareness, Situation-awareness.

1 Introduction

It is widely recognized that large proportion of publics begins to experience debilitating conditions such as chronic illness or disabilities. Developers of health care applications have long noticed this trend. Hence, many research projects have evolved to enable a health caring space, e.g. a smart ward, capable of observing surrounding context and thereafter making adequate decisions. Such capabilities are currently defined as being context-aware [1]. Most projects and prototypes percept the contexts in order to infer user intention, and do whatever necessary to help the user accomplish his or her tasks. As for the term "context", we use the definition proposed by Dey et al. [1], where a "context" is any information that can be used to characterize the situation of an entity which can be a person, place, or object. On the other hand, the term "situation" is the context that is derived from one or more contexts based on situation inference mechanisms (will be discussed in Section 3).

Bricon-Souf et al. reported that most of these context-aware health caring systems use only simple contexts (e.g. timing, human or artifact locations and

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states, user identification, and bio-information) which are too naive to infer human intentions [3]. Further, the contexts used are not well-organized, lacking context information leads to poor service quality. We therefore propose a new "situation-aware" caring system for smart wards where a "situation" refers to a new type of context extracted by knowledge-involved inference engines, given basic context information. Besides, the proposed system is constructed bases on ambient wireless sensor network for ultimate context perceiver, which differs from previous projects using wearable sensors (like RFID) or privacy-intrusive sensors (like cameras) to extract contexts. Further, the design of the proposed system is based on a highly extensible architecture called Message-Oriented Middleware (MOM). Hence, it is easy for application developers to deploy new components with minimal modifications to the overall system, which is one of the most critical requirements in real-world smart wards. As a result, these applications built based on the proposed system better satisfy the real demands from the medical professionals and caregivers.

2 Related Work

Situation awareness and extensibility are both important qualities of smart ward caring systems in a real-world environment. Although many systems or applications for smart wards have been proposed so far, few of them are both situation aware and highly extensible. Among them, Bardram et al. and Kjeldskov et al. [4,5] have carried out projects that assist medical works in a real-world hospital. These works use context-aware artifacts such as beds and pill containers. However, the information provided by the systems is limited to location-related contexts. Besides, a context-aware health care system for automating hospital message delivery is proposed by Munoz et al. [6], where location, time, role reliance, and artifact states are used as possible contextual elements for message delivery. Mitchell et al. [7] also proposed another prototype aiming for facilitating instant mobile communication between medical staff and patients by identifying roles by wearable active badges. The above-mentioned systems integrate context information in order to provide services. However, none of these works analyzes contexts in a systematic way, thus providing only limited information to caregivers. In this work we propose an extensible situation-aware system for a real-world hospital environment in which the software and hardware modules can be replaced on-the-fly and makes use of context in a more sophisticated way by deriving situations from contexts.

3 System Architecture

The overall architecture of the proposed system is depicted in Fig. 1a and Fig. 1b. Figure 1a is the horizontal view of the system where all modules interact based on MOM, which is an event-based mechanism that enables asynchronous communication and loosely-coupled integration. MOM creates a virtual "software bus" for integrating heterogeneous message publishers and subscribers, namely, the

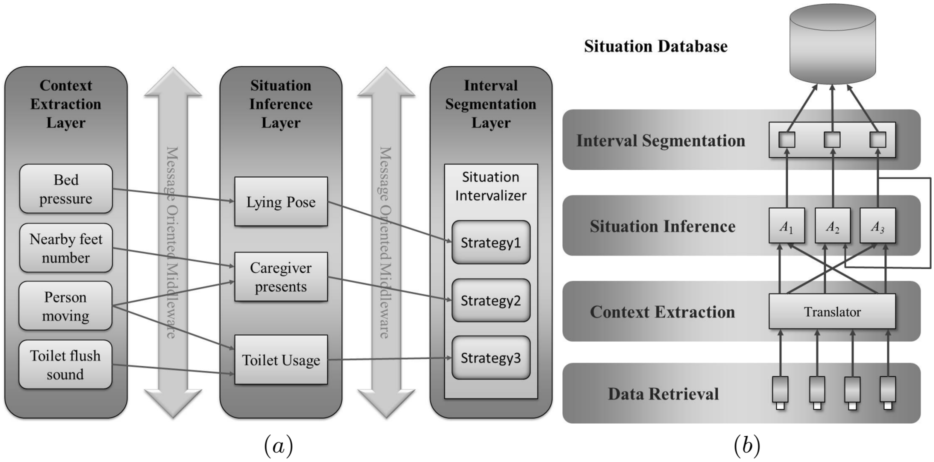

Fig. 1. The architecture the proposed system (a) Horizontal view; (b) Vertical view

"nodes". The logical pathways between nodes are called "topics". Based on this architecture, the system provides services by chaining nodes and topics together. Hohpe and Woolf [2] point out that when compared with other paradigms, messaging is considered more immediate than file transfer, better encapsulated than shared database, and more extensible than RPC-based invocation. Figure 1b provides a vertical view of the system which shows the data flow from bottom to the top, and then are persisted to a situation database. The persisted results can be categorized into two types: situation records and situation interval records. The former describes an environment state at a specific time whereas the situation interval records refer to a set of continuous environment events. In fact, the situation interval record is derived from situation records by Interval Segmentation. The detailed functionalities of each layer are explained below.

Data retrieval: A sensor network is deployed in the ward. A possible output of this layer looks like $[P_3, 0]$, which indicates a 0 read value for pressure sensor P_3 deployed on the mattress. In order not to interfere with patients' daily activities, the wearable sensors and privacy-intrusive sensors such as cameras should be avoided [8].

Context extraction: This layer consists of a set of components that translate the raw data into contexts. The translation logic is usually application specific. For example, one can determine a threshold and accumulate the values above the threshold. It is worthy to point out that translating continuous data (e.g. sound wave amplitude data) to a context such as "speaking". Sophisticate mechanisms based on pattern recognition are often used in this layer. A possible output of this layer can be $["upperbed", "off"]$, which indicates that the pressure sensor deployed on the upper bed is not pressed. The translated contexts are subsequently sent to a specific topic in the MOM.

Situation inference: Components belonging to this layer perform situation inference (usually by using machine learning techniques) from contexts. Specifically, this layer consists of several independently running inference components, each of them subscribes to a set of contexts or situation topics in MOM and is responsible for identifying a specific situation based on these data. For example, the situation ["*lyingpose*", "*leavebed*"] can be inferred after inspecting all pressure-related contexts (currently we mainly use HMM model, with input being a vector of 15 real number input from pressure straps, for recognizing all 11 possible pose states [9]). Note that some situations can be obtained by cascaded inferences. For example, if a situation ["*caregiverpresent*", "*false*"] is perceived, then ["*lyingpose*", "*leavebedalone*"] may also be inferred. Also note that since our system is designed based on MOM, one can easily extend the situation recognition capability of the system by introducing new inference components (See Fig. 1a).

Interval segmentation: Sometimes it is more informative to show the exact period of a specific situation to caregivers. This layer therefore exists for aggregating consecutive contexts or situations into one interval record. For example, ["*lyingpose*", "01/10, 12 : 03 : 54", "01/10, 12 : 15 : 39"] is a situation interval record. Since the segmentation process is usually application specific, we design this layer by applying the Strategy pattern [11] so that each situation interval type is handled by a specific segmentation strategy. This design improves the extensibility of the system. As part of output, the situation records, generated in situation inference layer, can be retrieved from the MOM. Meanwhile, the situation interval records can also be retrieved after persisted to the database.

4 Applications

In this section, we briefly introduce two real-world applications which has been built based on the proposed system. New situation-aware health care applications can be easily built based on the proposed system.

4.1 Situation Alerting

The first application called situation alerting is capable of notifying pre-configured alert event to caregivers, e.g. falling, so that caregivers can give help as soon as possible. Products [10] are there and proved to successfully detect target conditions, but they can not detect sophisticate situations such as "patient goes to bathroom alone and stays over 5 minutes" (possibly indicating an occurring accident). The application subscribes alert events from the MOM by specifying that only those situation records whose type matches the situation that is interested. Then, the monitored event list is adjusted accordingly. The current prototype is able to monitor the following situations: *Patient enters the bathroom (alone)*, *Patient leaves bed (alone)*, and *No caregiver presents.*

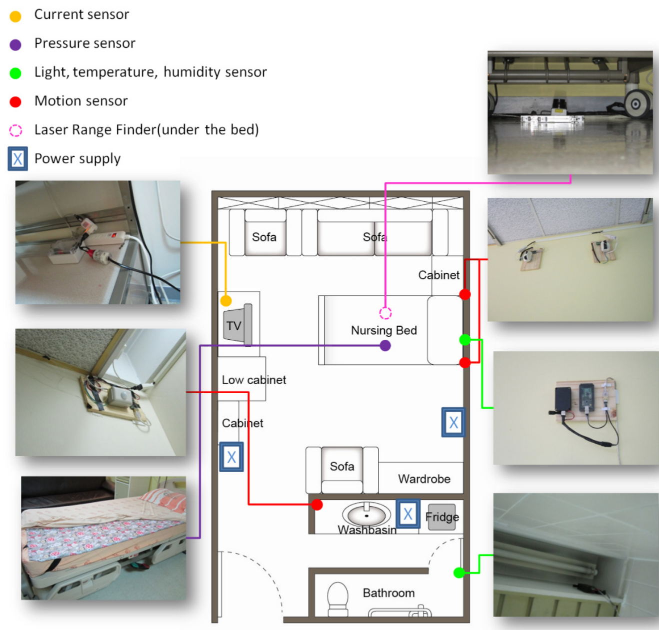

Fig. 2. The configuration of the real-world smart ward in NTUH

4.2 Situation Reporting

The second application is a reporting system that provides integrated view of patient situation by aggregating observed data and generating a graphical summary report. Traditional electrical medical reports offer only bio-related measurement information such as heartbeat rate or blood pressure. According to our preliminary interview to medical professionals, we notice that they require more informative and high-level information to assist them in making decisions. For example, clinicians may want to check if the total time leaving bed of a patient is at an increasing trend every day, and gives different prescription accordingly. We therefore design a Situation Reporting application that aims to fulfill this requirement. The summary report is mainly chart-oriented, and users can switch to different views based on their requirement.

5 Evaluation

In this section, we briefly introduce the deployment of our prototype to a smart ward of a real-world hospital, which evaluates the feasibility of the proposed system. Then, we present the results of preliminary surveys of satisfaction assessments as well as lessons learned when constructing this prototype.

5.1 System Implementation and Deployment

We have realized the proposed system and deployed it in the Rm. 9A03 of National Taiwan University Hospital (NTUH). To better assess the requirement of medical professionals and caregivers, we conducted several interviews with clinicians, nurses, and psychiatrists, for eliciting target situations that medical professionals emphasize most when evaluating the recovering progress. Based on the results, we chose to recognize the following situations: (1) Lying pose. (2) Bed leaving situations. (3) Rehabilitation conditions. (4) Caregiver presents. (5) Socializing related situations (TV watching, speaking). Fig. 2 depicts the configuration of the real-world smart ward (Rm. 9A03 in NTUH). Until the end of 2011, we have collected data for 12 complete independent cases of situational data, all of which are elders whose age is over 65.

5.2 Preliminary Satisfaction Assessment

To assess the satisfaction of the functionality and usability of our system, we conducted a questionnaire-based preliminary survey from nurses and nurse practitioners in NTUH. The questions are all around the two applications mentioned in the previous section, and was mainly designed for assessing the level of satisfactory on the original demands. That is, the agreement that the system indeed helps monitoring overall patient conditions. 22 respondents (2 males, 20 females) are interviewed, whose age ranges from 23 to 51. The survey result of the 22 interviewees is briefly summarized in Table 1. The item that directly relates to our goal is the second one, which gets an average score of 4.14, which indicates an agreement on the system usability (5 for total agreement), and effectively represents a positive assessment of our system of satisfying the need of helping caregivers monitoring patient situations. However, the overall satisfaction of the system as a whole is not quite as good. By interviewing the respondent deeper, they generally think that the system will be more probable when serving chronic patients than acute ones. The main reason is that caregivers serving acute condition patients tend to be busier, and to whom the system can be less instantly affective. As a preliminary survey, we believe that the reply is encouraging. In addition, we have learned many precious suggestions from medical professionals.

5.3 Lessons Learned

Experience shows that deploying and maintaining a caring system in a real-world environment is never an easy task. In the following, we report several issues and lessons learned we have encountered and learned so far regarding to a caring system in real-world smart wards.

Dealing with sensor malfunctioning: In real-world deployment, sensors used to gather context data fails periodically and must be replaced. Unfortunately, due to privacy and health issues, it is impossible for the technicians to enter the

Table 1. Summary of preliminary satisfaction assessment

Question Item	Average Score
Be satisfied with operations of UI	4.09
Be provided with better understanding of patient conditions	4.14
Be satisfied with overall system functionality	3.91
Think that the system can be used clinically by now	4.23

*1 for totally disagree; 5 for totally agree.

wards and fix the failed sensors when they are malfunctioning. Currently, we configure the sensors so that they send heartbeats periodically. In addition, we use redundant sensors to reduce the overall MTBF (Mean time between failure).

Dealing with power insufficiency: All devices need power, either AC or batteries, to keep on operating. As it is very difficult to ask clinic caregivers to replace the battery, AC is a better choice. Unfortunately, AC-based power supplement limits the location of sensors which is critical for the accuracy of situation inference. In addition, the government law also restricts the deployment of the length and numbers of additional wires. As a result, we suggest that the number of sensors should be as small as possible. Besides, the circuit of the environment should be customized to alleviate the power supplement issue.

Dealing with noises coming from the environment: Situation recognition mechanism can be inaccurate due to noises coming from the environment. For instance, we have deployed a sound sensor in the toilet for analyzing flushing sound. However, due to poor sound insulation, the sensor not only collects the sound of neighboring wards, but also collects the sound of the nearby aisle, corrupting the overall recognition accuracy. We suggest to carefully find the potentially source that the noise coming from, and then use more types of sensors to help increasing the accuracy. In the above-mentioned scenario, we introduce two motion sensors so that the recognition module only activates when someone is entering the toilet.

6 Conclusion

In this paper, we present preliminary results of the design and evaluation of a situation-aware caring system for real-world smart wards in NTUH. The architecture is designed so that the applications built based on the system is extensible. In addition, the system is capable of supporting hierarchical situation inference from simple contexts. Currently, we have implemented the system as well as two applications and then deployed them in a smart ward. Based on the preliminary survey results, we have learned many precious suggestions from medical professionals and observed that there are still many challenges regarding to users' satisfaction. Currently, we are improving the system usability and conducting the survey at a larger scale. In the future, we will also enhance the autonomy and reduce cost so that it can be widely deployed. In addition, we are also planning to integrate the system with a private cloud platform in the hospital to facilitate more interesting applications.

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