Monitoring Behavioral Patterns in Hospitals through Activity-Aware Computing

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Abstract—**Hospital nurses closely monitor patients to track their evolution and identify their needs. Based on a workplace study conducted in a hospital, we present the design of a mobile activity monitor aimed at creating a wearable ambient connection between patients and nurses. The system monitors patients' behavioral patterns and notifies nurses of relevant patient states through a bracelet wore by nurses. This bracelet works in pair with a cell phone to show information related to the activity being executed by patients. The results of a preliminary evaluation showed that nurses perceived the application to be useful and efficient and, the general idea seemed appealing.**

Keywords: activity recognition, activity-aware computing, behavioral activities patterns, hospitals

I. INTRODUCTION

Hospital nurses are highly mobile, spending more than 50% of their time on-the-move, making difficult for them to be aware of the status of the patients they are responsible for [1]. Therefore, nurses have been held liable for their failure to monitor and promptly respond to patients by informing physicians of significant changes in patients' conditions [2].

This has motivated the introduction of pervasive technologies in hospitals that allow nurses to closely monitor patients. These technologies range from wireless networks, PDAs [3], RFID tags for patient tracking [4], voice-activated communication devices [5], and sensors for patient monitoring [6]. For instance a hospital in Boston is testing an ultrasound tracking system that can determine patients' location and monitor their vital signs [4]. Widespread adoption of sensors that monitor the wearer's vital signs, other indicators and the activities being executed promise to improve care and reduce medical costs.

Activity-aware computing offers the opportunity to monitor the activities being executed by people. The core idea of Activity-aware computing is to allow "smart environments" to respond proactively to the needs and intentions of their users by being aware of the activity being executed. Hence, if we take the activity, as the central trigger, we will be able to infer the contextual information that is relevant as the users' course of actions evolves informing the adaptation process which contextual information can be associated with the users' current activity. Hence, to help hospital workers to successfully monitor patients' activities; activity-aware computing is becoming a central consideration for future developments in pervasive computing for healthcare.

To show the feasibility and value of activity-aware computing in hospitals, in this paper, we present the design of a mobile activity monitor that allows nurses to be aware of patients' status and activities while they are on-the-move. The system was developed based on the results of a case study conducted to understand the characteristics and behavioral patterns of the activities monitored by nurses. In addition, we present the results of a preliminary evaluation of the system discussing the nurses' perception towards the system's features and core characteristics.

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II. MONITORING BEHAVIORAL PATTERNS: A CASE STUDY IN HOSPITAL WORK

We conducted a field study to understand the way hospital workers monitor and assess patients. The field study was conducted in the Internal Medicine where approximately fifteen patients are registered and supervised by four nurses, one attending physician and five medical interns. The patients attended in this area, are generally elder people, senile and alone. They normally have a chronic or a terminal disease, such as renal failure, cerebral lesions or cardiac problems. Hence these patients are normally immobile and incapable of perform alone the activities of daily living.

This study was conducted for nine months were five nurses, five medical interns and five physicians were shadowed for two complete working shifts and interviewed by researchers. The total time of detailed observation was about 196 hours and 46 minutes. To understand the medical behaviors experienced by those observed, we conducted a qualitative analysis following the techniques to derive grounded theory. As a result of this analysis, we identified the patient's behavioral patterns monitored by hospital workers.

Activities monitored by nurses

Nurses are responsible for providing integral and specialized care for patients. As part of the integral care, nurses monitor the activities of the everyday living (ADL) conducted by patients, such as, if a patient has taken his medicine, if he has walked, fell from the bed, evacuated, etcetera. As a part of specialized care, nurses need to monitor the behavioral patterns in the activities that put in risk the patients' health or that indicate an internal failure which might evolve into a more serious disease (e.g., pneumonia, an apoplexy or a stroke), such as, if a patient is agitated or if he is bleeding. These behavioral patterns associated to risk activities (RA) are monitored through the vital signs.

Activities monitored are classified

Nurses are used to assign three levels of urgency (i.e., low, medium, high) to each of the activities monitored. For

instance, the ADLs are generally classified with a low level of urgency while the RAs are classified with a medium level being able to evolve to a high level. In addition, nurses make exceptions based on each patient disease. For instance, for a patient who has cirrhosis hepatic and that is immobile, monitoring his evacuations is very important since his liver does not function and nurses must avoid the formation of sores in his skin. Hence the classification of an activity might depend on the state of the patient.

Activities are monitored based on contextual information

Contextual information such as, time, measurements associated to an activity being performed and/or the patient state or disease, is used to determine the activities to be monitored. For instance a nurse explained during an interview *"some activities, at a particular moment, might not be urgent but they could become urgent after a period of time or depending of the patient condition or disease"*. Moreover, the condition of a patient sometimes indicates the activities that patients should not perform. For instance, if a patient has a cardiac problem he should not get up from bed. Hence, nurses must monitor when a patient with such disease is out of his bed or they need to be aware of his disease to bring him a wheel chair instead of taking him walking if the patient needs to move to another area.

Activities are monitored to collect information

Nurses need to compute and manage the information associated with the activities monitored. Therefore, the need for this information under several circumstances determines which activities must be monitored. For instance, a nurse explained: "*Sometimes, I do not need to monitor when the patient has eaten or drank instead I need to monitor how much he has eaten or drank"*. Hence, in this case the activity being executed by a patient only acts as a trigger alerting a nurse that she must gather the information associated to such activity.

III. THE MOBILE ACTIVITY MONITOR

The findings from the study were used to inspire the creation of a mobile activity monitor that allows nurses to promptly identify patient needs by monitoring the activities executed by patients. The system uses a bracelet which is attached to the wrist of a nurse (Figure 1a). This bracelet has five buttons with embedded lights. Each button represents a patient cared by a nurse. This number is appropriated since nurses are responsible for the care of four to five patients. Adapted from the medical model utilized in the emergency unit (i.e. triage), each light in the button turns on with colors analogous to a traffic light (i.e., red, yellow or green). Each light turns on based on the activity being executed by patients. Nurses can press the button to consult information associated to the activity being executed by the patient selected. This information is displayed in the nurse's cell phone (Figure 1b). Nurses may also use their cell phone to configure the colors of the bracelet, the activity they want to monitor and contextual information associated to such activity (Figure 2). To illustrate the system's characteristics and functionality, we elaborated several scenarios of use. In the following lines we describe one of them.

A. Monitoring behavioral patterns of the activities performed by patients

Carmen, the nurse in charge of Pedro, explains Rita, the nurse who just arrived for the night shift, that Dr. Perez, the attending physician, has changed Pedro's medication to include cyclosporine. Pedro is a 60 years old man, who has a chronic renal failure and just had a renal transplant. Hence, to monitor Pedro's reaction to the new transplanted kidney, Rita needs to supervise Pedro's urine output habits. Rita uses the activity-aware mobile assistant in her cell pone to specify that the light that represents Pedro in her bracelet must turn on yellow when Pedro evacuates and must change to red if Pedro urinates more than 5 times over a period of 6 hours (Figure 2b). Later, while Rita is preparing medicines, Pedro's light (i.e., the light that represents Pedro in Rita's bracelet) turns yellow. By pressing from her bracelet the button that represents Pedro, the activity being executed by Pedro is displayed in Rita's cell phone (Figure 1b). Rita realizes that Pedro has evacuated and that he has urinated 10 cc. Rita moves to the warehouse and gathers the medical equipment she needs to clean Pedro. Then, Rita moves to Pedro's room and changes Pedro's cloth. After that, Rita updates Pedro's liquid balance. Throughout the night, Pedro's light in Rita's bracelet constantly is turning yellow indicating to Rita that Pedro is urinating. A couple of hours later, while Rita is discussing the progress of a patient with Dr. Perez her bracelet turns red. Rita consults her cell phone and she realizes that Pedro has urinated 7 times in a period of 6 hours. Rita discusses with Dr. Perez the case of Pedro and he decides to change Pedro's medication to avoid damaging the newly transplanted kidney.

Figure 1. *The mobile activity monitor (a) A nurse using the activity-aware bracelet (b) The mobile activity-aware assistant*

B. The Activity-aware Bracelet

We decided to create a device that takes into account the mobility experienced by nurses during their work. We envisioned the Activity-aware Bracelet as a two layered vynilic bracelet which has attached five buttons (Figure 1a). Within each button a light is embedded. We developed our own components to achieve communication between the bracelet and the phone by reading frequencies under 27

Mhz. This will avoid interferences between the bracelet and equipment placed in the hospital or wore by patients. The information received by the bracelet specifies the color of the light. Three colors are used to convey the state of the patient based on the activity being executed. For exceptional cases, the meaning of the colors in the lights could be determinable by nurses. On button presses, a message is sent back to the phone specifying a patient id. Based on such id, the phone determines which activity should be displayed.

C. The Activity-aware Mobile Assistant

The activity-aware bracelet works in pair with an activity-aware mobile assistant embedded in each nurse cell phone. The activity-aware mobile assistant allows nurses to use their cell phone to configure and consult patients' activities, as well as, to estimate the activities being executed.

Figure 2. *The activity-aware mobile assistant (a) A nurse assigning colors to the activities being monitored (b) A nurse associating contextual information to the red light*

Consulting activities behavioral patterns

One of the challenges faced by nurses is to promptly identify their patients' needs and to be at the place when an emergency occurs. For instance a nurse commented: "*sometimes, I have patients that are placed in different areas of the hospital and if I am looking for a patient I am locked up in his room and I do not realize what is happening with my other patients, I am totally disconnected from those patients".* As shown in the scenario, when Rita realizes that Pedro has evacuated she decides to focus on Pedro instead of other patients (Figure 1b). Therefore, Rita is able to assign priorities and to be connected to the patients she is responsible for based on the information shown by the system. In addition, Rita is able to consult information associated to the activity being executed by a patient

Associating contextual information to monitor activities

As we discuss, activities are classified and monitored based on contextual information. Hence, it is important to enable nurses to associate contextual information to the activities they want to monitor. As shown in the scenario, Rita is able to classify the activities she is monitoring by assigning colors to them (Figure 2a), as well as, being notified when particular actions occur or after a series of events happen (Figure 1). Besides, nurses can assign other contextual information to a previously selected light. For instance, when Rita uses her cell phone to specify that her bracelet must turn red when Pedro urinates more that 5 times over a period of 6 hours (Figure 2b).

Estimating the activities performed

To estimate the activity being executed, we developed an approach that takes the information gathered from the workplace study as seed data to train pattern recognition algorithms [7]. To exemplify our approach we train and test two pattern recognition algorithms (i.e., a neural network and a hidden markov model) for activity recognition.

The first approach uses a back propagation neural network (NN) which is trained to map from contextual information (i.e., the location of hospital staff, artifacts being used, the people with whom they collaborate and the time of the day) to activities performed by hospital workers [7]. The results of activity recognition using NN indicate that we can correctly predict hospital workers' activities 75% of the time (on average). The second approach was developed with the aim at improving our activity recognition accuracy. To overcome this, we use HMM instead of NN as the engine to estimate hospital workers activities [8]. The results of activity recognition using HMM indicate that the user activity can be correctly estimated 92.6% of the time.

IV. PRELIMINARY EVALUATION

We evaluated the bracelet design, the system's core characteristics and the nurses' intention to use the system. To do this, we conducted long interviews that lasted from 30 minutes to one hour with seven nurses. Before the interview begun, the general idea behind our system was explained and two scenarios illustrating the context and the usage of the system were presented.

A. Systems' design and system features

Table 1 shows the nurses' perception towards the system's core characteristics and features.

TABLE I. NURSES' PERCEPTION TOWARDS THE SYSTEM'S FEATURES

Nurses perception / Questions	*Agree*	*Disagree*
Is the bracelet a device appropriate instead of another device?	2	5
Is it useful to have a light for each patient instead of one for all the patients you are responsible?	4	3
Is it useful to be notified by colors using the traffic light analogy?	6	1
Receiving alerts and flashlights can distract me from my work?	0	7
Is it hard to assign an alarm to the activities executed by patients?	0	7
Is the information shown by the phone enough?	5	2
It would be easy to learn how to use the system?	7	0

Despite one can infer from table I that nurses may did not like the bracelet, nurses did recognize that they really enjoy having the combination of the bracelet and the cell phone, their disagreement was more related to how this technology might affect patients or other technology already placed in the hospital. For instance, some nurses differ in using a

bracelet attached to their wrist, using only colors to notify events and in using one light for each patient assigned to them. For example, a nurse explained: *"I like the idea of a bracelet because I can monitor everything while I am mobile, but I would prefer to use the bracelet above my elbow. This would cope with several problems and would not interfere with digitalized devices attached to the patients, such as monitors or even a pacemaker wore by a patient"*. Nurses also explained that it might be better to have one light in the bracelet to notify an event and then in the cell phone consult the information associated to such event, others explained that having several lights will save time. In this regard, a nurse explained: *"If I only have one light I would have to consult the cell phone to find out the problem with the patient, having one light for each patient is more direct and will save me time"*.

B. Additional insights gathered during the session.

Nurses validated both scenarios and provided us with additional insights for applying our technology.

Enable users to use the system as a remainder service

Nurses explained that this system would be also useful to remember pending tasks. They expressed that it is very common to forget tasks during their shift and sometimes these small tasks they forget could evolve into a serious problem. For instance a nurse explained: *"We forget so many things in a shift because we have so much to do, for instance the medicine schedule. Suddenly it is almost 2pm and you forgot to administer the medicine dose at noon, because you did not have anything that reminds you"*.

Enable the seamless integration with fixed systems

Nurses explained that they are used to have the technology directly attached to the patient to avoid problems and errors. Nurses explained that having the information in the cell phone might cause problems, because they might confuse the patient they are attending with another because they are not in front of the patient. For instance a nurse explained: *"I prefer for the bracelet to only function as an indicator because we are mobile but instead of consulting the information of the patient in my cell phone I would prefer to consult this information in the room of the patient. In this case I would be sure that the problem I am handling corresponds to such patient"*.

V. DISCUSSION AND CONCLUSIONS

In this paper, we show the feasibility of activity-aware computing in hospitals by presenting the design of an activity-aware application that takes advantage of activity recognition to establish a wearable ambient connection between patients and nurses. The results of a preliminary evaluation helped us to gather additional insights to improve our system, as well as, to see that only when people have a picture of how the system could enhance their work they can envision advantages and disadvantages in using it.

All the nurses interviewed explained that the bracelet will help them to save time, avoid errors and increase the quality of attention provided to patients. A nurse commented: *"this bracelet will improve the quality of attention, the work will be the same, but I will do the work faster and whenever is needed. For instance if a patient has evacuated I can not know until I smell something odd or I have to ask him or guess. In this case I would promptly know the patient needs and I can even take with me the things that I would need instead of being wondering around"*. In addition, nurses noticed that the system will allow them to assign priorities to the events occurred with the patients assigned to them. A nurse explained: *"Something that we currently can not do is to identify which patient has to be attended first; a system like this one will help me to identify the urgency state for each of my patients"*.

Despite that nurses explained that this system will have more advantages than disadvantages, nurses were to some extent worried about the negative issues that this system might raise. A nurse explained: *"I do not like these things because I am a nurse who likes her job and we need to give the highest quality of care, warmth and affection to the patient, and with this type of systems the emotional bounds and the relationship between nurse and patient are lost, the warmth might be replaced by quality"*.

Despite that these issues were pointed out, the overall application was perceived to be useful and efficient and, the general idea seemed appealing. Nurses repeatedly express that this system will solve a lot of the problems they currently faced and that they can not wait to have this system ready to use it. They expressed that the incorporation of this system in their everyday practices will truly improve their work. A nurse explained: *"this is something that we have been waiting for so long, because this will help us with patient care instead on supporting secondary tasks as the other systems currently introduced do"*. Using the results of the evaluation, we plan to improve our design and to implement a prototype which will react based on the patients' activities. In addition, we plan to evaluate this application within the hospital to assess the impact of activity-aware computing in hospitals.

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