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Sleeping Patterns Observation for Bedsores and Bed-side Falls Prevention

Aung Aung Phyo Wai[1], Kow Yuan-Wei[2], Foo Siang Fook[1], Maniyeri Jayachandran[1], Jit Biswas[1] and John-John Cabibihan[2]
[1]Institute for Infocomm Research, [2]National University of Singapore

Abstract—**Disabled or cognition impaired elderly may lie in the bed most of their time. It is important to monitor their health conditions and look out for life threatening events in and around the bed continuously. Abrupt unassisted movements may lead to falls whereas the lack of desirable movements may cause bedsores. In order to alleviate these problems, we propose automated means of continuous and unobtrusive sleeping pattern observation through pressure sensing bed. By understanding of subjects' states from observed pressure evidences, timely intervention and nursing care can be provided to subjects immediately. This enables provision of high quality care to frail and dependent elderly, and also enhances their quality of life in a cost-effective and resource-efficient manner.**

I. Introduction

THE rapid growth of elderly population [1], shortage in care-giving manpower and high healthcare costs are the most pressing issues in today's geriatric care. The focus of this paper is on the problems related to bed-ridden elderly. Due to decline in both physical and mental abilities, some elderly are not allowed to leave the bed without assistance. But elderly may suffer problems related to falls when they are trying to get out or move from the bed without caregiver attendance. On the other hand, they are often unable to make the desirable bodily movements and repositioning that are critical for blood circulation and relieving of prolonged pressure over the body. Thus two critical conditions, namely bedsores [2] and bed-side falls [3] commonly occur among bed-ridden elderly due to lack of desirable nursing care and immediate attention. For these reasons, continuous observation of the bedridden elderly is necessary in order to prevent the abovementioned adverse effects.

Pressure sensing is commonly used to monitor context and behavior of subjects on bed or chair. The observed pressure evidences can assist in determining the adverse health conditions of subjects. So pressure sensors are ideal for monitoring in a continuous, unobtrusive and unrestrained manner, the conditions of elderly persons lying on their beds. Upon detection of undesirable or dangerous situations, care-givers may provide required nursing care in a timely fashion. At the same time they are relieved from having to continuously monitor the bedridden elderly.

In this paper, we present a solution for continuous observation of bedridden elderly using a low-cost pressure sensing system. In [4], pressure sensors are used to observe various activities and locations of the subject in home environments. [5] performs analysis with simple low cost pressure sensors in order to classify subjects' body position effectively. Also, 3-axis wearable accelerometer is used in [6] to estimate sleeping posture, but it can only measure coarse granularity posture and is obtrusive to use in long-term care settings. Our solution differs from the above approaches in that we observe sleeping patterns of the subject to infer subject's interactions with the bed, and we also detect potentially dangerous situations.

The remainder of the paper is structured as follows. The challenging healthcare issues and overview of sleeping pattern observations will be presented in sections 2 and 3 respectively. Experimental results and discussion are provided in section 4. Finally we conclude the paper with a discussion on merits of our approach and provide some directions of future work based on our current efforts.

II. Healthcare Issues and Challenges

In long-term care settings, care-givers are ideally required to observe the elderly around the clock to prevent bedsores and falls. They have to provide prompt attention when the elderly has urgent needs. But it is very difficult to provide that degree of surveillance and attendance required by the elderly all the time. The varying knowledge and personality of caregivers also affects quality of nursing care and consistency with which care is provided from time to time.

Lack of timely care and insufficient preventive measures taken by human care-givers leads to unfortunate consequences to be suffered by the elderly and also indirectly affects their family members. This can lead to further escalation in the already mounting healthcare costs for the government, and degradation of Quality of Life (QoL) for the elderly. In the remainder of this section, we discuss these problems in greater detail, ending with a possible solution that uses bed pressure sensing.

A. Bedsores

Bedsores can be mainly caused due to unrelieved or constantly applied pressure over bony and bedsore-prone areas of the body. Bedsores are regarded as one of the serious diseases and take a long time to completely heal [7]. Patients who do not exert normal movements or repositioning of their limbs to relieve sensitive areas, are prone to suffer from bedsores. The basic problem arises because the subjects do not have adequate self-consciousness or control of pressure over bedsore prone areas. They also cannot reposition themselves and relieve pressure from sensitive areas, which therefore suffer from constant applied pressure over prolonged periods as shown in Figure 1.

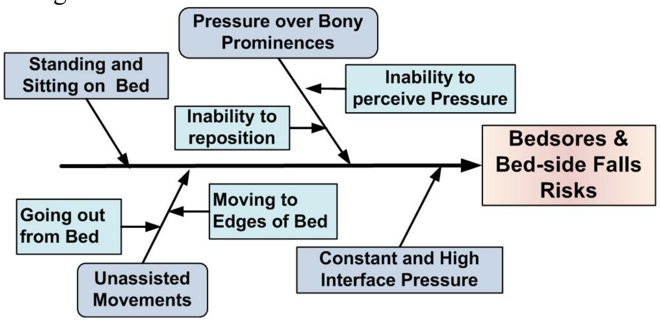

Figure 1: Relation of pressure to bedsores and bedside-falls risks

In order to avoid the occurrences of bedsores, it is required to observe potentially bedsore prone areas of the body. As shown in Figure 2, sleeping pattern/posture is directly related to the bedsore prone areas of the body. By knowing posture of the subject, potential bedsore risks of the subject can be inferred and timely reminders can be sent to care-givers. So, appropriate interventions can be provided for areas that experience undesirable pressure [8].

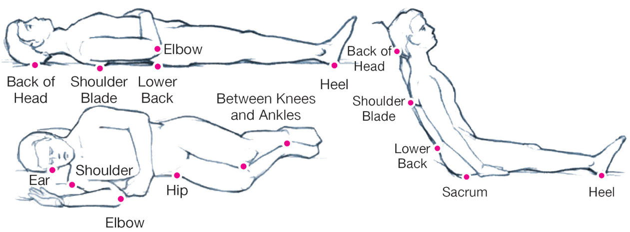

Figure 2: Bedsore prone areas with respect to subject's sleeping posture

B. Bed-side Falls

Falls are the most common and major healthcare problems for both physically and cognitively impaired elderly who live alone at home or care institutions. There are various efforts to prevent falls using wearable sensors and video cameras [9][10]. But these approaches are not suitable for long-term care settings due to issues of privacy and obtrusiveness. Although falls may take place at any place and at any time, we confine our attention to falls occurring in and around the bed. Bed-side falls mainly occur while the frail elderly, who are supposed to get assistance from care-givers, try to get out of bed without attendance. If the elderly tries to sit or stand from sitting position, there is a high chance of a fall.

In order to prevent falls [11], the position of the subject with respect to the edge of the bed must be observed continuously. Alerts or reminders should escalate while the subject shows a tendency to move towards the edge, and so, care-givers have some time to respond to the patients with immediate attention. Similarly, while the subject is not completely lying on bed such as sitting on the bed or trying to get out of the bed, the care-givers may be alerted as well.

The above discussions motivate the need for fine-grained sleeping patterns observation to determine potential health risks with measurements taken from pressure sensing bed. From observed pressure evidences, subject and application specific decisions may be made to enable timely preventive nursing care (Figure 3). System refinements may be made to the pressure sensing bed in order to adapt to the needs of a subject. In this manner, appropriate preventive care can be delivered in a timely fashion, and without much extra cost.

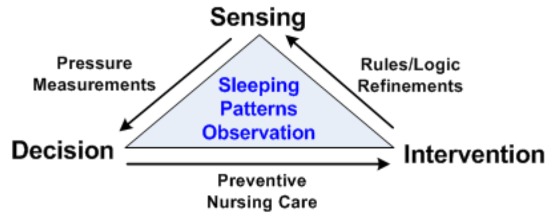

Figure 3: Considerations on sleeping patterns observation system

III. SLEEPING PATTERNS OBSERVATION

Pressure sensors generally provide intensity readings of applied load exerted by the subject. From the pressure sensor data spatial and temporal parameters are extracted to determine conditions and situations of the subject. Thus a pressing sensing bed provides us an enabling tool for unobtrusive and unrestrained monitoring by observing pressure evidences relating to bedsore and bed-side falls, as shown in Figure 4. We see four main topics in interpreting pressure information obtained from pressure sensing: a) posture classification, b) body position identification c) body orientation monitoring and d) movement detection.

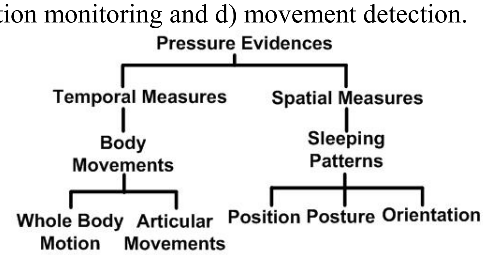

Figure 4: Patient's Parameters measured by evidences from pressure sensors

A. Posture Classification

Sleeping posture plays an important role in identifying the risks of bedsore caused by interface pressure. From correctly identified sleeping posture, the areas with high potential bedsore risks can be inferred. From detected sleeping posture sequences over a specific duration, the activities or behaviors of the subject can be determined [12]. The identified posture with movement detection can predict potential bedsores and bed-side falls as well as wakefulness, such as tossing and turning for sleeping activity monitoring.

B. Body Position Identification

While the subject is lying in either lateral or straight position on the bed, the relative body position with respect to the bed can be identified through measuring high pressure intensities with spatial identities from pressure distribution. This provides valuable cues for bed-side falls prevention where the fall risks are highly related to position of the subject with respect to the edge of the bed.

C. Body Orientation Monitoring

In actual care environments, a subject may not be lying straight in one direction along the bed. The orientation with respect to the bed may vary from one person to another. The coupling of orientation aspect into posture classification enables the unconstrained determination of sleeping pattern of the subject. The orientation can be measured relative to the dominant pressure distribution with respect to the bed layout.

D. *Movement Detection*

The activities performed or movements exerted by the subject are important indicators for preventing bedsores as well as bed-side falls. If there is no activity or movement, there is high likelihood of there being constant and prolonged pressure over various parts of the body. Abrupt movements of the subject near the bed edge also constitute high risks of bed-side falls for the elderly. The movements detection may be classified into fine-grained, articular movements and coarse-grained, body movements.

IV. Experiments and Discussion

In order to evaluate how sleeping patterns observation helps in preventing bedsores and bed-side falls, we have conducted a set of experiments using our customized hardware and developed software system.

A. *Pressure Sensing Bed*

We have implemented a low-cost, wireless and easily deployable pressure mat with Force Sensing Resistors (FSR) [13] using Wireless Sensor Network (WSN) platform. Figure 5 shows how multiple FSRs are configured and deployed on a bed for observing pressure distributions of a subject lying on the bed. Because of wireless internetworking capabilities, this pressure mat can be extended to multiple beds as well as on wheelchairs. The form factor of the mat, as well as the number and geometry of pressure sensor deployments can be easily altered in order to customize the system. In order to detect the dangerous situations of bed-side falls, long FSRs are placed in perimeters and circular FSRs are placed with equal spacing on remaining areas of the bed.

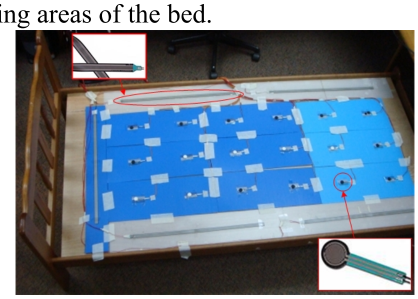

Figure 5: WSN-based Pressure Sensing system deployed on the bed

B. *Processing of Pressure Data*

Figure 6 illustrates the software architecture for processing measurements from a set of pressure sensors to observe the patient's spatial and temporal states. The software modules are divided into two main categories: sensors processing and activity recognition.

Sensor processing modules process direct pressure readings to extract features and identify primitives relevant to the subject. Activity recognition infers the spatial and temporal states of the subject from pressure evidences and provides intervention according to actual care needs.

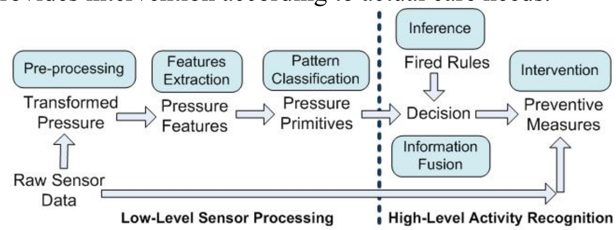

Figure 6: Software modules for bedsores and bed-side falls applications

Application and contexts specific rules are used with pressure evidences to infer the healthcare risks applicable to the subject as well as desired timely interventions. The following code excerpts demonstrate how rules are used to determine bedsore risks and interventions relevant to subject.

```
E1: If(Bed, hasSurface, Hard)→ (Environment, hasBedRisk, Medium)
S1: If(Subject, hasPosture, supine)→(Subject, hasBedRisk, Medium)
                    .........
SE1:If(Subject, hasBedRisk, Medium) and
       (Subject, hasMovement, NIL, wth30min) and
        (Environment, hasBedRisk, Medium)→ Warn Care Givers
```

Figure 7: Sample Rules to determine bedsore risks and intervention

C. *Sleeping Posture/Position Identification Approach*

In this section, we discuss on how sleeping pattern is determined through different stages of pressure information processing. Principal Component Analysis (PCA) and descriptive statistical analysis are used to extract spatial pressure features specific to each posture. Then, Support Vector Machine (SVM) classifiers with Radial Basis Function (RBF) kernel is used to classify the intermediate sleeping postures. Finally, the resultant sleeping posture is determined by fusing the outputs from classifiers with different feature inputs as shown in figure 8. Similarly, descriptive statistical features are used with spatial layout of the bed to determine the ellipse that represents sleeping position of the subject. For preliminary motion recognition, significant pressure points are identified first. Then, linear regression is used to identify the motion according to changes in both spatial and intensity features of the mapped pressure points.

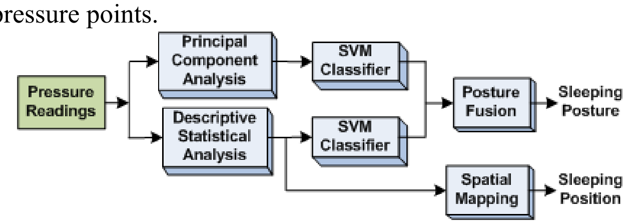

Figure 8: Sleeping Posture/Position Identification Approach

D. *Experimental Results*

The different posture types, as shown in Table I, according to varied spatial granularities are considered to test and evaluate our posture classification method. Then, a set of pressure data are collected from mockup trials with a few participants to determine posture classification accuracy. Variations in body orientation are not considered for now.

Table I: Postures considered For posture classification

Directional Posture	Posture	Body Shape
FreeFaller	Prone	Straight
Soldier	Supine	
Starfish		
Left Foetus	Foetus	Lateral
Right Foetus		
Left Log	Log	
Right Log		
Left Yearner	Yearner	
Right Yearner		

The experimental results in Figure 7 provide the average posture classification rate over different types of sleeping postures [14] as described in Table I. The same sleeping posture classification and fusion approach is applied to evaluate posture classification accuracies according to different posture types.

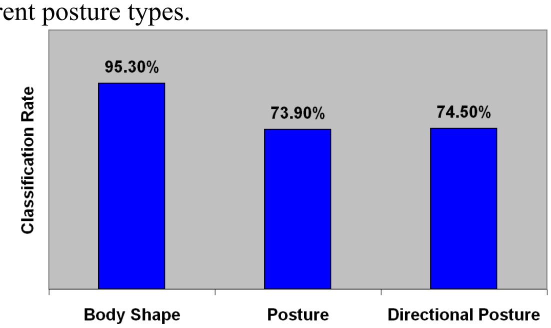

Figure 7: Average sleeping posture classification accuracies

Moreover, the position detection can accurately provide the relative location of the subject on bed by comparing with real subject images as shown in Figure 7. The represented ellipse can measure the relative orientation of the subject's body on the bed as well as movements along the detected body position. Because of only straight orientation with different postures, Figure 8, is collected in experiments, the orientation monitoring cannot exhibit full extents of their capabilities. We are currently collecting data with different positions and orientations to evaluate orientation monitoring.

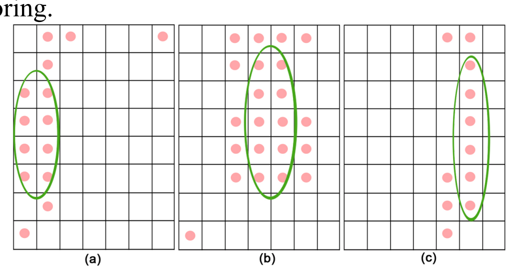

Figure 8: Body position identification (a) Subject lying in left (b) Subject lying in center (c) Subject lying in right

In this manner, a thorough evaluation will be done in future with different sets of sleeping postures with different orientations. Although we have developed movement recognition algorithms to capture the subtle movements, and further work is still required to accurately distinguish between desirable and dangerous movements.

E. Future Work

The same observation system can be used on wheelchair to extend the observation of patient's pressure profiles and contexts of movement. As of now, we have only considered falls that may occur while the subject is getting out of bed. Falls may also occur while the patient is sitting on a commode or wheelchair nearby the bed, and trying to move to the bed on their own. Bedsides applied interface pressure, other extrinsic and intrinsic factors may cause bedsores. Also, it is advisable to consider those with pressure evidences for effective bedsore prevention. Another direction we are currently investigating is the use of ambient sensors such as Passive InfraRed (PIR) and ultrasound sensors to observe the subjects' movements and behavior on the bed.

V. CONCLUSION

This paper presents sleeping patterns observation for bedridden elderly in order to prevent bedsores as well as bed-side falls. The elderly subjects' conditions and events detected from pressure evidences can assist care-givers to provide timely preventive care to the elderly. This can fulfill our main objective of providing cost-effective and care-efficient ambient assisted living environment to help the frail and cognitive impaired elderly achieving better Quality of Life.

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