Behavior Analysis in the Elderly Care Center Using Kinect Depth Sensor

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***Abstract*—The demands of elder care and long-term care are increasing as the population of elder persons is increasing. However, nursing personnel of an elderly care center have to take care of many elders in some countries. A falling accident may occur without notice by the personal in the night. It caused the problem of lawsuit or compensation. Behavior analysis of an elderly on the bed is useful to solve the above problem. A method is proposed and a prototype is developed by utilizing Kinect depth sensor in this paper. A state diagram is defined to model the behavior. When two states, sitting on the bed and getting out of bed, are detected, a siren can be issued to remind the nursing personnel for preventing the possible accident. The Kinect depth sensor can be operated in the dark environment and enables the system can monitor the behavior of an elder all the time. In addition to the dangerous behavior, all the possible behaviors can be monitored by the prototype for providing any further services. A set of testing videos with various scenarios is used to evaluate the performance. The experimental results show that the proposed method can analyze the behaviors of an elderly with high correction rate.**

***Index Terms*—healthcare, conservation center, behavior analysis, depth sensor**

I. Introduction

The population of elderly people is increasing quickly in the modern world. Many elderly persons are enrolled in the elderly care center for some reasons. However, the number of nursing personnel in the day is usually smaller than that in the night. A falling accident may occur without notice in the night. According to the previous study, a fall might be due to variety of reasons like muscle weakness, impaired activities of daily living [1]. The falling detection, recognition, or even prevention is important issues for the elderly population.

On the other hand, the Kinect depth sensor is popularly used in many applications. For example, S. Wang *et al.* proposed a method for detecting the stairs, crosswalks, and traffic signs by using the RGB-D (depth) image of the depth sensor [2]. R. Lloréns *et al.* proposed an approach of virtual stepping for balance recovery [3]. The Kinect sensor can still be used to acquire the depth data in the dark environment and enables the monitoring or behavior analysis operating in 24/7 mode.

Therefore, the depth sensor is suitable for analyzing the behavior of elder people in the night. In this paper, a state diagram is designed to model the behavior of elderly. The state transition is triggered by analyzing the ROIs (Region-of-Interest) of the depth data. The proposed method is expected to prevent the possible accident, especially falling of elderly, in the night.

II. Related Studies

Some previous utilized the Kinect sensor for specific purpose. For example, A. B. H. Mohamed *et al.* proposed a system using Kinect sensor for assisting disabilities in the home environment [4], [5]. Kinect sensor is used to recognize the gestures of disabilities for assisting to control devices in a smart home.

M. Parajuli *et al.* proposed a health monitoring system using the Kinect sensor [6]. The health condition of an elder can be collected from the posture recognition (sitting or standing) and gait recognition (normal or abnormal walking). In advance, the fall of an elder can also be detected by the proposed system.

T. Banerjee *et al.* proposed a fall detection technique using the Kinect sensor in the real hospital [7]. Firstly, the foreground is extracted from the depth images. The foreground forms the 3D point clouds. Features are then extracted from the 3D cloud and inputted to a fuzzy rule-based inference system for detecting the possible fall event. R. Dubey *et al.* also proposed a method for fall recognition by using the depth camera [8]. However, fall prevention should be better than the fall detection. It is too late when a serious injury occurs.

D. Webster and O. Celik reviewed Kinect applications in elderly care [9]. They provided an overview of the state of the art, limitations, and issues of concern as well as suggestions. Authors concluded with overall remarks regarding use of Kinect in elderly care and reported a summary of critical issues and suggestions for future work in this domain.

III. System Design

The system is designed for monitoring the elder's behavior on the bed. The basic system architecture is

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shown in Fig. 1. A Kinect depth sensor is used to monitor the behavior of an elder. Then, the depth data is acquired and analyzed by the system. A siren alarm is triggered by the system to notify the nursing personnel to ensure the safety of an elder.

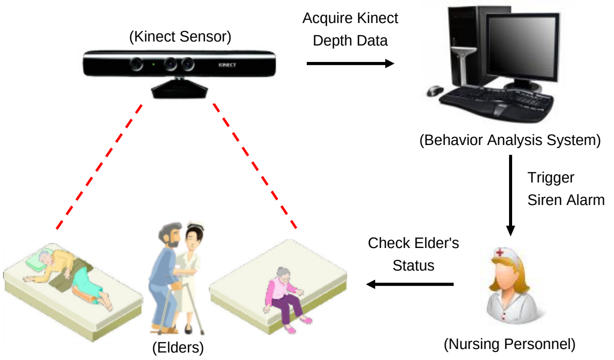

Figure 1. System architecture.

The process of the behavior analysis system is shown in Fig. 2. The process is based on a predefined state transition diagram for modeling the behavior of an elder on the bed. Several states, such as nobody, lying in the bed, sitting on the bed, are included in the diagram. Therefore, the depth data is analyzed to check whether the transition condition is satisfied, then the state transition is performed. If the state is dangerous, for example, sitting on the bed in the midnight, a siren alarm will be trigger to remind the nursing personnel.

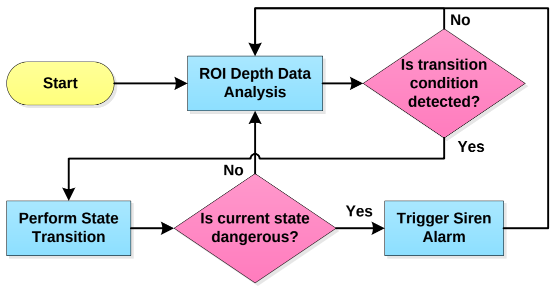

Figure 2. System process.

The state transition diagram is very important for the behavior analysis in this paper. According to the observations in the elder care center, an elderly person may lie in the bed, sit on the bed, or get out of bed. A caregiver may do an exercise program with an elderly person. Therefore, six possible states are defined and listed below and the state transition diagram is depicted in Fig. 3:

1) Nobody: There is nobody on the bed. It is the initial state of the diagram.
2) In bed: An elder is in the bed.
3) Lying in bed: An elder is lying in the bed.
4) Sitting on the bed: An elder is sitting on the bed.
5) Out of bed: An elder gets out of bed.
6) Caregiver care: A caregiver is caring an elder.

The demonstration of possible state transition is shown in Fig. 4. Initially, nobody is in the bed. Then, a man who is pretending to be an elderly person is entering the FOV and lying in or sitting on the bed. A caregiver is entering the FOV to take care of the elderly person. After the leaving of the caregiver, the elderly person is sitting on the bed and then leave the FOV.

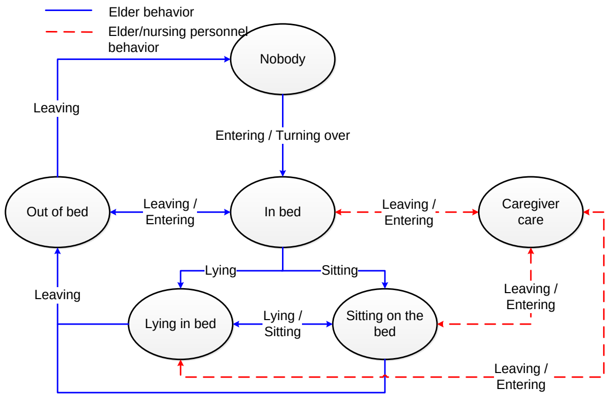

Figure 3. The state transition diagram for elderly behavior modeling.

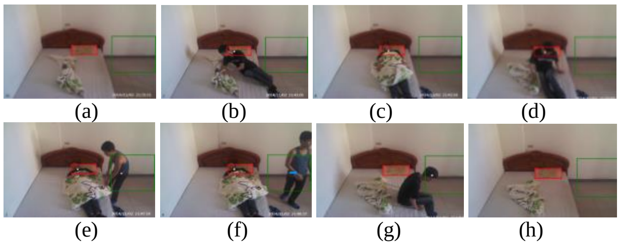

Figure 4. Demonstration of possible state transitions (a) nobody (b) entering FOV (c) lying (d) sitting (e) caregiving (f) caregiver leaving (g) getting out of bed (f) nobody.

IV. Methods

In order to analyze the behavior of elderly, two kinds of ROIs are designed. One is red ROI and the other is green ROI, denoted as ROI_R and ROI_G, respectively. The ROI_R is used to detect the possible events, including: sitting, lying, turning over, entering, and leaving. The ROI_G is mainly used to detect the entering and leaving of a person. An example of the ROI_R and ROI_G setting is shown in Fig. 5.

Figure 5. The setting of ROI_R and ROI_G.

A depth image is two-dimensional data. A depth data of a point is a positive integer, the unit is millimeter. There are more events to be detected in ROI_R than in ROI_G. Therefore, all the depths in ROI_R without the elderly are recorded as the baseline values, denoted as B. Then, the difference of the real-time depth data and the baseline values are computed. A point, $P(x, y)$, with the difference larger than a threshold, α, is marked. If the ratio of all the marked points, i.e., D_{ratio}, is larger than another threshold, β, the event *sitting* is detected. If is smaller than the threshold γ, the event *lying* is detected. Otherwise, the event is *turning over*. The above computation is represented as (1) and (2).

$$D_{ratio} = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\begin{cases}1, if\ |P(i,j)-B(i,j)|\geq\alpha \\ 0, otherwise\end{cases}}{M\times N} \quad (1)$$

$$Event = \begin{cases} sitting, if\ D_{ratio} \geq \beta \\ turning\ over, if\ \beta > D_{ratio} \geq \gamma \\ lying, if\ D_{ratio} < \gamma \end{cases} \quad (2)$$

Besides, the entering of leaving of the elderly and nursing personnel or caregiver is also analyzed. The analysis is mainly based on the moving direction of the centroid in ROI_G. The centroid of all the marked points is computed by using (3) and (4). Here, only the x-coordinate of the centroid, denoted as C_x, is computed since only the moving direction is derived from the successive C_x. The moving direction, $\overrightarrow{C_x}$, is used to determine the event is either *entering* or *leaving*.

$$C_x = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\begin{cases}i, if\ |P(i,j)-B(i,j)|\geq\alpha \\ 0, otherwise\end{cases}}{\sum_{i=1}^{M}\sum_{j=1}^{N}\begin{cases}1, if\ |P(i,j)-B(i,j)|\geq\alpha \\ 0, otherwise\end{cases}} \quad (3)$$

$$Event = \begin{cases} entering, if\ \overrightarrow{C_x}\ is\ toward\ to\ the\ bed \\ leaving, if\ \overrightarrow{C_x}\ is\ away\ from\ the\ bed \end{cases} \quad (4)$$

Therefore, the state transition is based on the event detected in ROI_R and ROI_G. For example, if the initial state is “Nobody”, and an *entering* event is detected, the state is transited to “In bed”. If another *entering* event is detected again, it means the caregiver is caring the elder. Therefore, the elder is still in “In bed” and the state “Caregiver care” is also triggered. If the *lying* event is detected, the state of the elder is transited to “Lying in bed” state. Once the caregiver is *leaving*, the state is transited back to the current state of the elder.

TABLE I. THE DESCRIPTIONS OF ALL THE TESTING VIDEOS

No.	Time	Subjects	Description
1	Day	Caregiver/ Elder	Caregiver helps elderly going to bed Caregiver cares the elderly twice.
2	Day	Caregiver/ Elder	Caregiver helps elderly going to bed and caring the elderly.
3	Day	Caregiver/ Elder	Elderly goes to bed himself and then caregiver is coming to care the elderly.
4	Day	Caregiver/ Elder	Elderly goes to bed himself and then caregiver is coming to care the elderly.
5	Day	Caregiver/ Elder	Elderly goes to bed himself and then caregiver is coming to care the elderly.
6	Day	Caregiver/ Elder	Elderly is lying on the bed, and sits, and then cared by the caregiver.
7	Day	Caregiver/ Elder	Elderly is sitting and then cared by the caregiver.
8	Day	Elder	Elderly is sitting on the bed and someone walks passing the bed.
9	Day	Elder	Elderly is lying, sitting, and then leaving the bed.
10	Day	Elder	Elderly sits on the bed when the system is started.
11	Day	Elder	Elderly lies on the bed when the system is started.
12	Night	Elder	Elderly enters FOV and sits on the bed, and then leaves.

V. EXPRIMENTAL STUDY

In order to evaluate the performance of the proposed method, a prototype is implemented and a set of testing videos is recorded. The recording is using the Kinect Studio, the video and depth data can be recorded and playback synchronously. It is convenient to repeat a testing video and find out the possible problem. The descriptions of the all the testing videos are listed in Table I.

There are 12 testing videos. Twelve videos are recorded in the day and one is recorded in the night. Seven videos are related to the elderly and caregiver and six videos are elderly only. Various situations are recorded to ensure the correctness of the proposed method. Although the depth sensor can be operated in dark environment, it is unnecessary to record all the videos in the dark environment. The image is needed to ensure the behavior the elderly. A series of screenshots demonstrate the results of the prototype as shown in Fig. 6.

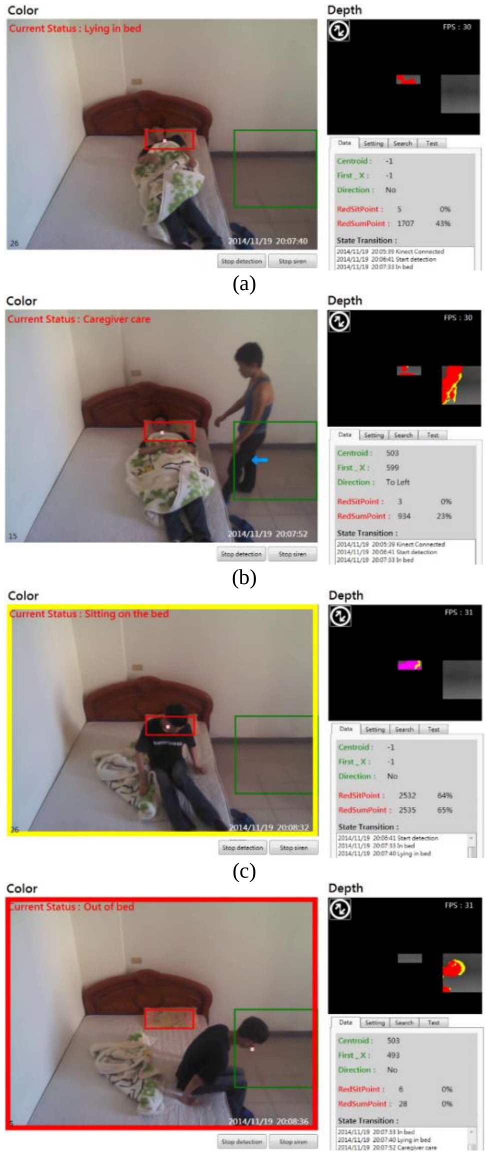

Figure 6. A series of screenshot of a testing video (a) lying in bed (b) caregiver care (c) sitting on the bed (warning) (d) out of bed (Siren).

TABLE II. THE NOTATIONS OF STATE TRANSITIONS

State	State Transition	State	State Transition
S1	Nobody→In bed	S10	Out of bed→In bed
S2	In bed→Lying in bed	S11	Nobody→Caregiver care
S3	In bed→Sitting on the bed	S12	In bed→Caregiver care
S4	In bed→Out of bed	S13	Sitting on the bed→Caregiver care
S5	Sitting on the bed→Lying in bed	S14	Lying in bed→Caregiver care
S6	Sitting on the bed→Out of bed	S15	Caregiver care→In bed
S7	Lying in bed→Sitting on the bed	S16	Caregiver care→Nobody
S8	Lying in bed→Out of Bed	S17	Caregiver care→Lying in bed
S9	Out of bed→Nobody	S18	Caregiver care→Sitting on the bed

The delay of the state transition is also measured visually. All the state transitions of testing videos are listed in Table II. The error count of the transitions is listed in Table III. The delay of these transitions is listed in Table IV. There are two values in some transition. It means there are two times of transitions in the testing video. The average delay of transitions S1~S18 are depicted in Fig. 7.

TABLE III. THE ERRORS OF STATE TRANSITIONS

No.	Transition sequence	Total	Error
1	S11, S17, S14, S17, S14, S16	6	0
2	S11, S17, S14, S16	4	0
3	S1, S2, S14, S17, S7, S6, S9	7	0
4	S1, S3, S5, S14, S17, S14, S16	7	0
5	S1, S3, S5, S14, S16	5	0
6	S1, S2, S7, S13, S18, S13, S16	7	0
7	S1, S12, S15, S12, S16	5	0
8	S1, S2, S14, S17, S7, S6, S9	7	0
9	S1, S2, S7, S5, S7, S6, S9	7	1
10	S1, S3, S5, S7, S6, S9	6	0
11	S1, S2, S7, S6, S9	5	0
12	S1, S3, S5, S8, S10, S4, S9	7	1

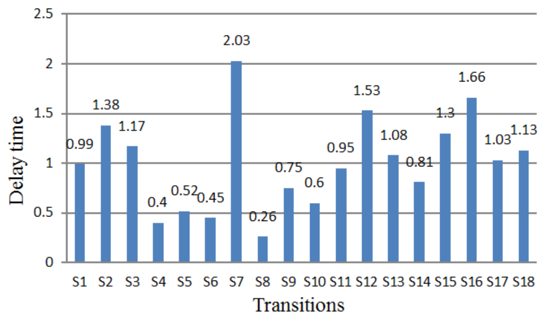

Figure 7. The average delay in seconds of all the transitions.

TABLE IV. THE DELAY OF STATE TRANSITIONS (ST)

ST \ No.	1	2	3	4	5	6	7	8	9	10	11	12
S1			1.5	0.63	1.1	1.73	1.13	0.56	0.7	0.46	0.83	1.26
S2			1.7			1.93		1	1.66		0.63	
S3				0.93	2.33					0.76		0.66
S4												0.4
S5				0.43	0.7				0.66	0.23		0.56
S6			0.6					0.33	0.46	0.26	0.6	
S7			3.56			2.86		2.16	2 0.6	0.86	2.16	
S8												0.26
S9			1.1					0.53	0.86	0.66	0.6	0.76
S10												0.6
S11	0.96	0.93										
S12							1.26 1.8					
S13						1.5 0.66						
S14	1.06 0.73	1.46	0.66	0.3 0.53	1.1			0.6				
S15							1.3					
S16	1.93	1.53		1	1.63	1.93	1.96					
S17	1.11	1.33	1.5	0.63				0.56				
S18						1.13						

(unit: seconds)

By observing these results, the following remarks can be made:

- Only two transition errors are found among 73 transitions in the experiment. It shows that the correctness of the proposed method is very high. An error occurs in testing video No. 9. Two transitions S7 (Lying in bed→Sitting on the bed) and S6 (Sitting on the bed→Out of bed) are expected to be detected. However, the transition is S8 (Lying in bed→Out of bed) under a parameter setting. The parameter is the minimal interval of a transition from one state to another. The elderly sits on the bed two short and then moves away from the bed. That is why the state "Lying in bed" is transited to "Out of bed" directly. In fact, the setting can be adjusted to avoid such error.
- Most of the transitions can be finished in a short period. It shows that the proposed method can be operated efficiently.
- The longest average delay S7, Lying in bed→Sitting on the bed, is 2.03. The elderly is usually slowly sitting up from the lying state. So,

the transition is done when the depth change is larger than the threshold shown in (1). It is a reasonable delay.

VI. Conclusions

The elder care is becoming an issue in the modern world. The falling accident is also frequently occurred to the elderly. In this paper, a method is proposed by using the Kinect depth sensor for behavior analysis of an elder in the long-term care center. The Kinect sensor can be operated in the dark environment and suitable for monitor the behavior in the night. A state diagram is defined to model the behavior of an elder person in the bedroom.

The experimental results show that the proposed method can analyze the behavior with a high correctness. The transitions can be done in a very shot delay. It provides enough time for reminding the nursing to prevent the falling accident of the elderly when the elderly is sitting on the bed.

In the future, the proposed method can be used to enhance the services of the care center. For example, the log of daily states can be recorded for the relatives to realize the life of the elderly. A real-time image or live video can be sent to the children of the elderly when the state is "Caregiver care" for ensuring the service quality of the care center.

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