Detection of a Person Awakening or Falling Out of Bed Using a Range Sensor

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ABSTRACT

In this paper, we describe a monitoring system for bedridden persons that utilize a proximity range sensor with an infrared projector and is capable of detecting persons awakening and/or falling out of bed. The system, which utilizes an optimal linear discriminant function, has demonstrated a detection rate of 98% for the targeted behaviors. It is believed that this system will be useful for monitoring seriously ill and/or elderly persons in hospitals and private homes that must occasionally be left unsupervised by healthcare professionals or family members. The wandering of elderly persons suffering from dementia can also be detected and averted.

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1. INTRODUCTION

Demand is increasing for methods of monitoring bedridden seriously ill and/or elderly persons in hospitals and private homes. In hospitals, if a person who is seriously ill awakens, it is important that the responsible healthcare professionals be made aware of that fact because such patients may fall out of bed and suffer serious injuries. Elderly persons being cared for by family members at home can be injured in the same way. Furthermore, the wandering of elderly persons suffering from dementia is a serious social problem. However, full 24-hour supervision by healthcare professionals in hospitals, or by family members at home, is difficult to provide.

In this paper, we describe a monitoring system for bedridden persons that can detect awakening behaviors and can sense when persons are in danger of falling out of bed. Currently, numerous types of monitoring systems are available or have been proposed [1-8]. These include passive camera-based image processing systems, mat sensors, and ultrasonic sensors. However, the recognition rates for passive camera-based systems and ultrasonic based systems are unimpressive and mat sensors are subject to mechanical failure. Here, we propose a monitoring system using a range sensor with an infrared projector.

2. RESEARCH METHOD

Figure 1 shows the experimental setup of our system. A range sensor with an infrared projector (Kinect, Microsoft Corp.) is positioned on the ceiling above the bed. The ceiling height is 240 cm above the floor level and the bed is 30 cm high. Test subjects, covered with a quilt, are positioned lying in the bed.

To simulate the case of a bedridden patient, the volume, space, maximum bed height, and patient information are first recorded and stored in the system memory. Next, the following changes related to the subject's positions are recorded: (a) patient lying on his/her back, then changing to the following positions, (b) lying on side, (c) sitting up, and (d) falling out of the bed. The range data were measured twice for each of these four cases for each subject. The absolute and relative values were then calculated. Five male and one female subjects participated in these experiments. Obtained data was analyzed via an optimal linear discriminant function (OLDF). Figure 2 shows the measurement process used for data analysis.

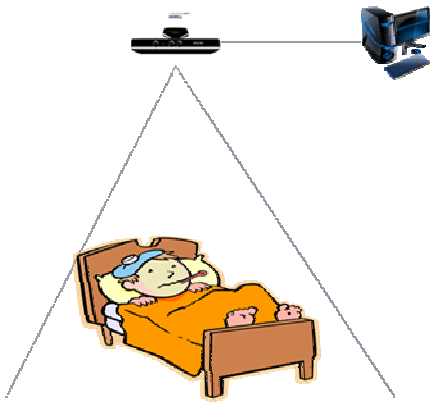


Figure 1. Effects of selecting position switching under dynamic conditions

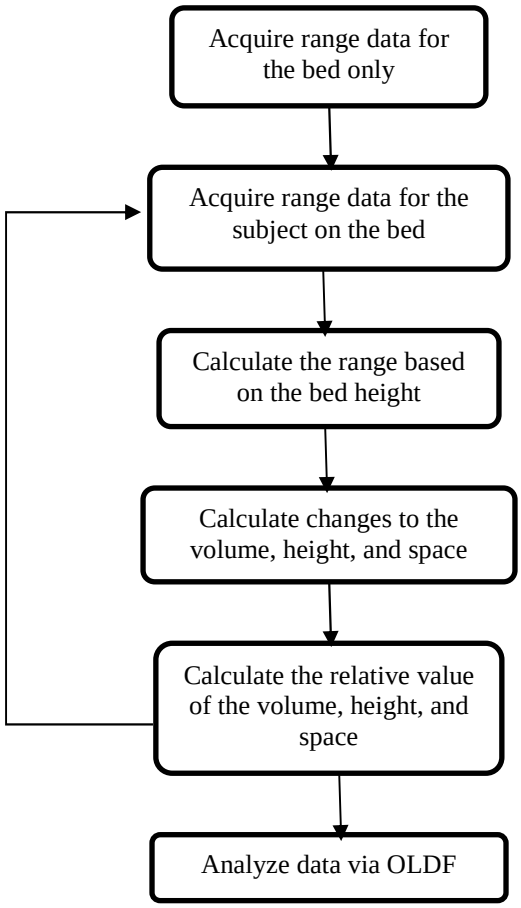


Figure 2. Measurement process used for data analysis

3. RESULTS AND ANALYSIS

Figure 3 shows the range image data for the bed itself. Figures 4 (a) and (b) show the camera image and range image for a bedridden subject lying on his back. As can be seen in the figures, range variations become notable.

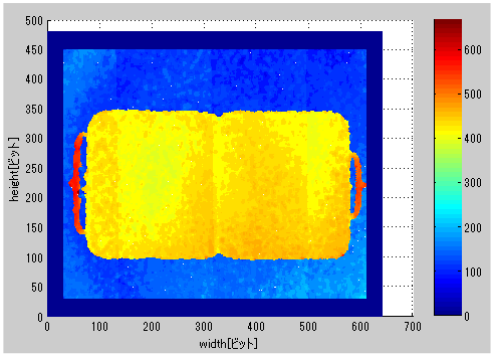
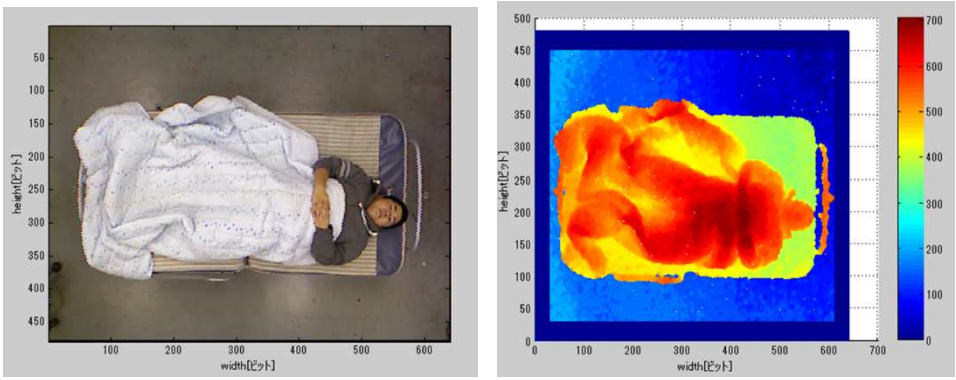


Figure 3. Range image for the bed

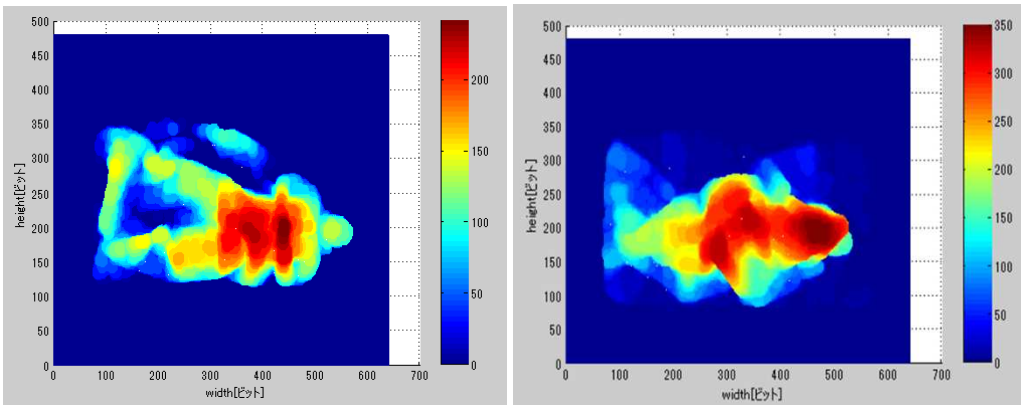


(a) Camera (b) Range image

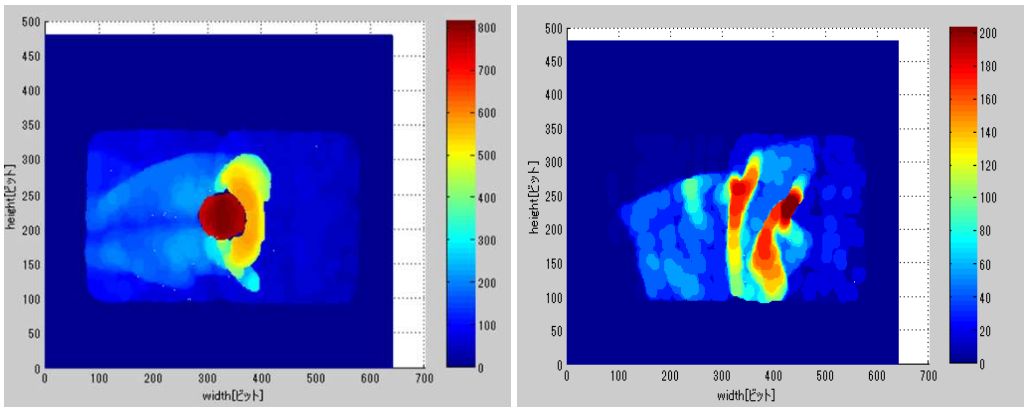
Figure 4. Camera image and range image for the bed

By subtracting the range image without a subject (Fig. 3) from the image with a subject (Fig. 4 (a)), a range image such as shown in Fig. 5(a) is obtained. Figures 5 (b), (c), and (d) show the subtracted range images when the subject is in other positions. Specifically, (b) shows an image of the subject lying on his side, (c) shows an image of the subject sitting up, and (d) shows the subject falling out of the bed.

When the subject is lying on his side, the height value becomes slightly higher. When the subject is sitting up, the height value becomes very high. When the subject falls out of bed, only the quilt is detected. As a result, the height value decreases slightly and the space variations become somewhat smaller.



(a) Subject lying on back (b) Subject lying on side



(c) Subject sitting up (d) Subject falling out of bed

Figure 5. Subtracted range images

Table 1 shows data for a subject obtained using the measurement process. Table 2 shows the relative changes to the data. The sitting condition can be detected using the value change to maximum height, which increases significantly. The falling out of bed condition can be detected using the volume value change, which decreases significantly.

Table 1. Absolute change to measurement data obtained via the senso
(Note: changes are calculated based on data for a subject lying on his/her back.)

	Lying on back (Position change)	Lying on side	Sitting up	Falling out of bed
Volume change (cm^3)	7,688	81,486	66,653	-91,583
Space chance (cm^2)	-229	1,955	-2,499	2,459
Maximum height change (cm)	3.3	23.5	55.7	-8

Table 2. Relative change to data obtained by via sensor measurement
(Changes are calculated based on data for a subject lying on his/her back.)

	Lying on back (Position change)	Lying on side	Sitting up	Falling out of bed
Volume change (%)	104	135	131	52
Space change (%)	99	109	89	113
Maximum height change (%)	116	194	352	96

OLDFs were found for combinations of two absolute or relative data values, and the resulting efficiencies were evaluated by the Shapiro-Wilk test. Table 3 shows the Wilks Coefficients for the combinations of two of three absolute change data and three relative change data. As can be seen in the table, the smallest coefficients of 0.0090 were obtained for OLDFs with relative volume and absolute height changes.

Table 3. Wilks Coefficients for each combination…

	Absolute volume	Relative volume	Absolute space	Relative space	Absolute height	Relative height
Absolute volume						
Relative volume	0.0620					
Absolute space	0.1026	0.0888				
Relative space	0.2175	0.0631	0.2123			
Absolute height	0.0146	0.0090	0.0117	0.0092		
Relative height	0.0422	0.0184	0.0435	0.0266	0.0356	

The discriminant functions become as follows:

$$u_{lb} = 0.059306 \times x_{ah} + 28.71124 \times x_{rv} - 21.413 \quad (1)$$

$$u_{ls} = 0.10256 \times x_{ah} + 34.86084 \times x_{rv} - 41.2457 \quad (2)$$

$$u_{up} = 0.237491 \times x_{ah} + 34.95733 \times x_{rv} - 119.817 \quad (3)$$

$$u_{fo} = 0.033068 \times x_{ah} + 2.048445 \times x_{rv} - 1.892243 \quad (4)$$

Here, u_{lb}, u_{ls}, u_{up}, and u_{fo} are discriminant values for the conditions of lying on back, lying on side, sitting up, and falling out of bed, respectively. x_{ah}, while x_{rv} are the absolute change of the height and relative change of the volume, respectively. The original condition of the subject is modified to the condition in which largest value is obtained by these equations.

Figure 6 shows the test results of the system for six subjects. M1 to M5 are the male test subjects, and W1 is the female test subject. Each subject was measured twice for each of the four conditions (eight measurements total). Equations 1 through 4 are used to determine the conditions of the subjects. The detection rate is 98%, the error rate is 0%, and the loss rate is 2%. With regards to the loss case, although the subject fell out of the bed, the quilt remained on the bed and the high maximum height and large volume of the range image remained stable. It does not concern the sex. Accordingly, the condition was indistinguishable from that of a subject lying on his/her back.

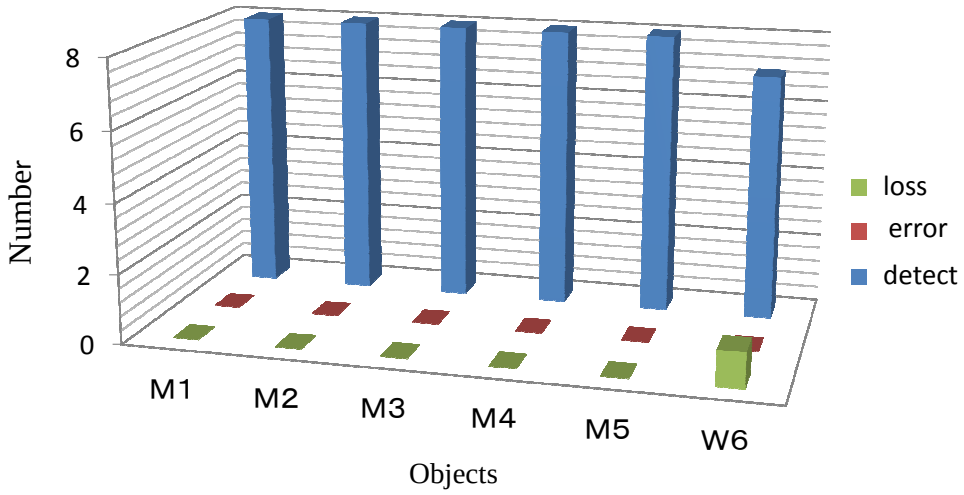


Figure 6. Test results for six subjects

4. CONCLUSION

In this paper, a monitoring system using range sensor with an infrared projector capable of detecting the behaviors of a person awakening and/or falling out of bed was proposed. The obtained data was analyzed by OLDF. Experiments using the system recorded a detection rate is 98%, thus proving its high reliability and practicality. It is believed that the system will be useful for monitoring seriously ill patients or elderly people in hospitals and private homes that must occasionally be left unsupervised by healthcare professionals or family members. The wandering of elderly persons suffering from dementia can also be detected and averted. For further verification, investigation using more samples is required.

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