Bed angle detection in hospital room using Microsoft Kinect V2

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***Abstract*—This paper will focus on bed angle detection in hospital room automatically using the latest Kinect sensor. The developed system is an ideal application for nursing staff to monitoring the bed status for patient, especially under the situation that the patient is alone. The patient bed is reconstructed from point cloud data using polynomial plane fitting. The analysis to the detected bed angle could help the nursing staff to understand the potential developed hospital acquired infection (HAI) and the health situation of the patient, and acquire informative knowledge of the relation between bed angle and disease recovery to decide appropriate treatment strategy.**

I. INTRODUCTION

Hospital-acquired infection (HAI) is a lethal factor in disease recovery for hospitalized patient in US. In 2002, the Centers for Disease Control and Prevention (CDC) estimated 1.7million patient acquired HAI and 6% of them died each year. In 2011, 722,000 patients got an infection from their stay in an acute care hospital. Although the number decreased, 10% of them died as a result of HAI. 22% HAIs are developed from hospital acquired pneumonia (HAP) [1]. For the patient, a longer time of staying in the hospital room comes out with a higher risk of being exposed to an infection.

Pneumonia has multiple names in different development stages and clinic manifestations. The healthcare-associated pneumonia (HCAP) is the pneumonia developed in a healthcare facility. It is different from the community-acquired pneumonia (CAP). HCAP includes hospital-acquired pneumonia (HAP) and ventilator-associated pneumonia (VAP). HAP is defined if patient doses not incubate pneumonia at the time of admission and develops pneumonia 48 hours or more after admission. VAP is defined for the pneumonia that appears more than 48-72 hours after endotracheal intubation. Some HAP patient may become VAP patient after intubation. HCAP occurs on patients admitted in hospital for 2 to 90 days of infection, resided in a long-term care facility or attended dialysis center. HAP will be developed into VAP when the pneumonia becomes serious and the patient needs to use intubation. We will use the concept of VAP in the paper to describe the pneumonia in hospital room. Ventilator-associated pneumonia (VAP) is the most serious one. Currently, VAP is still the main factor to cause morbidity and mortality [2].

Patients spend majority of their time on hospital bed during their hospital stay in the hospital room. The hospital bed status is very import. The recovery speed and health status of the patients is related to their in-bed activities. For example, in-bed time could indicate how serious of the disease for a patient. For those who suffer from their disease may get fatigues and need lots of sleep. A good quality of bed-rest can be evaluated by the less restless motions during a certain time period. The observed high frequency of the patient bed-exits may indicate that the patient acquires the urinary tract infection and needs to go to bathroom frequently. This list can be extended based on the health condition of each patient. To investigate this kind of information, the first essential step is to research on the bed status.

Studies have shown that there is a close relation between the bed raise angle and hospital-acquired infection (HAI), such as pneumonia. It is a controversy of raising the degree of the bed. The recommended backrest elevation for VAP patient is not less than 30 degrees. But the suggested backrest elevation should be less than 30 degrees for a pressure ulcers patient. A higher elevation may prevent the infection source to get into the lung, but it could result in thromboembolism or hemodynamic instability. The nursing staff needs to adjust the bed chair elevation angle according to the disease and situation of the patient from time to time [3-5].

Our purpose is to prevent the pneumonia by monitoring the bed chair angle without increasing the risks of getting other HAIs in hospital room. Sensor technologies based intelligent system has shown promising result in detecting elderly falls or measuring fall risk assessments [6]. Some of those sensors have been installed in a real living home to find the functional decline among the aging population [7].

On the market of patient bed monitoring system, a bed-exit alarm system and a proposed system based on multi-modal sensors are available. Those systems are promising in performance, but they still have many drawbacks. The bed-exit alarm systems are expensive and require a reinitialization for the patient's reenters to the bed. It also needs to be reinstalled after the bed is positioned at a new location. The multi-modal sensors are also pricy, not easy to deploy and intrusive for the patients.

Researcher designed the bed sensors using hydraulic tube transducer or electronic pressure sheet to monitoring the heart rate and breath for the subject lying on the mattress [8-9]. Those sensors are applicable for a living home, but has some limits in hospital room in humidity condition, bed status (both of them need a flat top to receive the body pressure), frequency move request from care giver. The method using the vision based surveillance camera system provides a feasible way to detecting the hospital bed using edge detection

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technique [10]. For better privacy protection, a Kinect 360 based bed status is also proposed based on edge detection on the depth image [11]. The edge detection based method performance is poor or not accurate when the bed edge is occluded by someone or beddings. This paper is focus on using point cloud data to detect the bed chair elevation angle via plane fitting with Kinect v2 sensor.

This paper is organized as follows. Section II introduces the bed related activities, shows the scene represented by point cloud, and gives the methodology. Section III presents the results of the patient bed angle detection. We generate the conclusions in section IV.

II. Methodologies and Data Collection

We collect data from a simulated patient room to validate the proposed method as seen in figure 1. This room has a similar size to the actual room that we are going to deploy the system later. The patient bed is positioned on one side of the room against the wall. The subject was asked to perform different activities in a role of patient.

A. Bed Related Activities

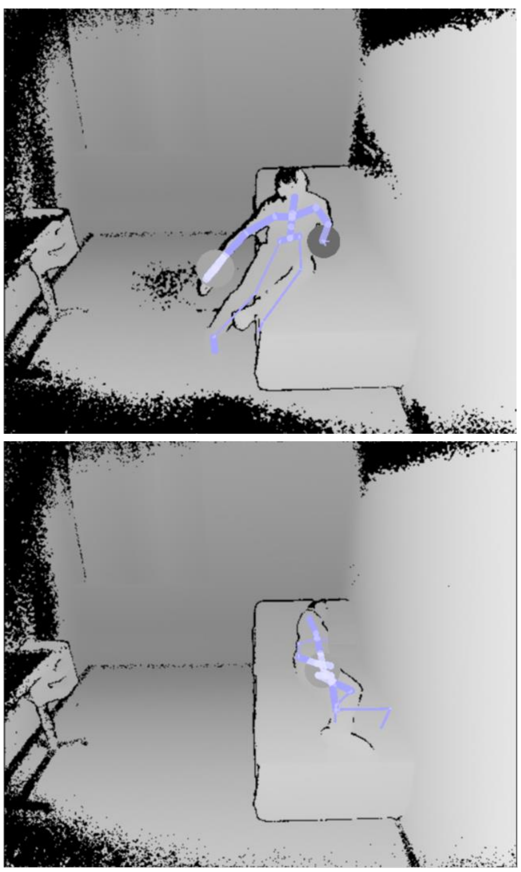

Figure 1. The bed-related activities in hospital room.

We have researched on out-of-bed behaviors in [12]. We are interested in understanding patient in-bed related behaviors (IBBs). Figure 1 shows the typical procedure of entering bed. This behavior includes a sequence of those activities: sit down on one side of the bed edge, put both legs on the bed, move both arms to bed center, move butt to bed center; move legs to bed center, and lay down.

A typical procedure of existing bed would be in a reversed order: rise up upper body, put both legs on the bed edge, move arms to bed edge, move butt to bed edge, and put foot on the floor. Those two behaviors usually come with a group of sequential activities. The recognition of those two behaviors could help to find out relation between the patient bed time and infections. Other in-bed behaviors are also important of contracting infections. For example, a bacterium infection occurs since the patient might not clean the hands before eating food on bed. This paper will only focus on the bed part, which plays an important role in IBBs.

B. The Scene with Point Cloud

Point cloud could be obtained by overlapping the depth and color images if the depth camera and color camera are located at same position. Otherwise, the alignment to those two cameras is necessary. Those two cameras are at different locations on the device. Since Microsoft has provided API for this, we could extract point cloud data directly. In figure 2, the point cloud represents a scene in hospital room. The origin of the coordinate is the location of Kinect. The depth direction or Kinect facing direction is aligned with Z-axis. The heightof the device is aligned with Y-axis. The device body is aligned with X-axis. In this scene, the bed is placed at the left corner and a patient desk is on the right side against the wall.

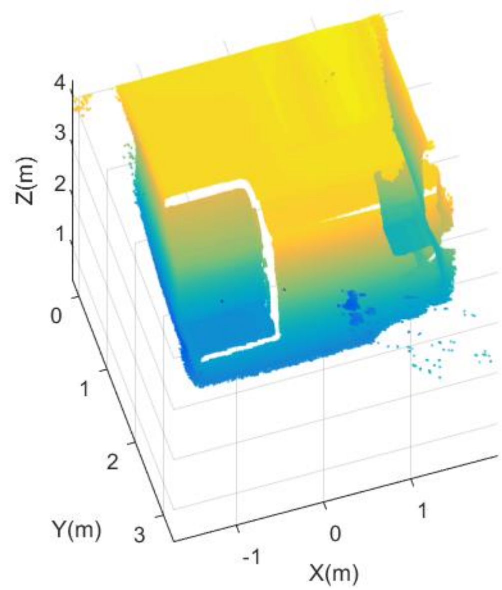

Figure 2. The point cloud of the scene in hospital room. This room is the same one with a mirrored relation to the room in figure 1.

C. Polynomial Plane Fitting Method

Figure 3 shows the selected region of interests (ROIs) from figure 2 since we are only interested in the hospital bed. By tilting the direction of the bed, we have a better view to the bed surface. The upper part is the bed chair and can be elevated by push-button on bed. Ideally the lower part of the bed should be aligned with the bed base frame, which is parallel to the floor.

The hinge between the bed chair and lower part is composed by two small support planes, which support the mattress with a curved transition angle and ensure a comfortable backrest for patient. This special design can be clearly observed from the side view of the bed in figure 4. The ground truth of the bed angle is measured under the assumption that the lower part of the bed is parallel to floor plane. Then the problem is simplified as finding the plane of the bed chair.

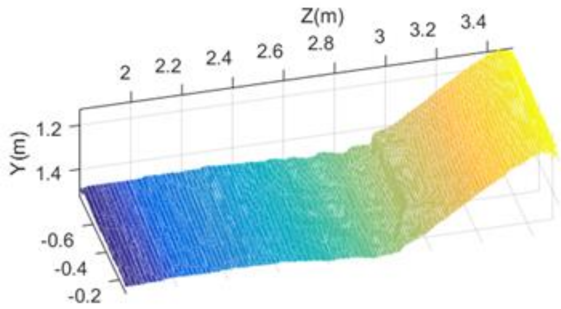

Figure 3. The ROI including the bed point cloud.

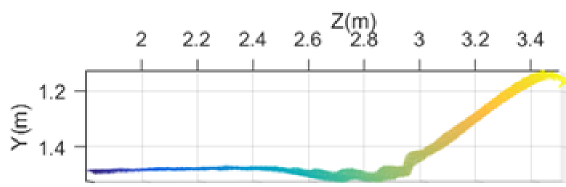

Figure 4 The side view to the bed point cloud.

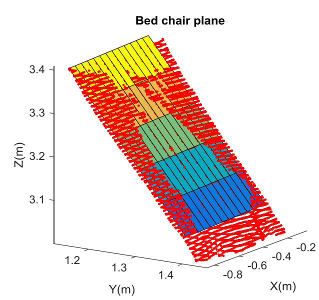

Figure 5. Fitting the bed chair point cloud with a polynomial plane.

A polynomial model can be described with equation 1. By fitting those point cloud on bed chair in figure 5, we find this plane parameters A, B, C and D with a normal vector $\hat{n}_1 = [A, B, C]$. The normal vector for the floor plane is $\hat{n}_2 = [0, 1, 0]$. The angle of the bed chair can be calculated using equation 2. The fitting parameters are [0.0121 -1.3850 -1.0000 4.9932]. The bed chair angle is 35.83^0 .

$$AX + BY + CZ + D = 0 \quad (1)$$

$$\theta = cos^{-1}(\hat{n}_1 \cdot \hat{n}_2) = \frac{A_1A_2+B_1B_2+C_1C_2}{\sqrt{A_1^2+B_1^2+C_1^2}\sqrt{A_2^2+B_2^2+C_2^2}} \quad (2)$$

III. Experimental Results

In this experimental part, we collect the point cloud data by changing the bed chair angle at 9 positions. The ground truth is measured with an angle measurer for each position. The estimated angle is produced from our proposed method.

The experimental results are listed in Table 1. The last column gives the percentage error in the range of [0.95%, 15.92%]. In figure 6, we show a comparison between our experiments and the ideal result. It is observed that a larger error occurs when the bed angle is less than 30^0 or larger than 48^0.

Table 1 Estimated Bed Chair Angle (The unit is in degree)

Index	Measured	Estimated	Error
1	54.00	48.63	0.0994
2	50.00	47.71	0.0457
3	47.10	46.65	0.0095
4	46.90	44.66	0.0478
5	41.80	42.63	0.0198
6	37.90	38.79	0.0234
7	37.10	35.57	0.0411
8	32.00	32.37	0.0116
9	25.50	29.56	0.1592

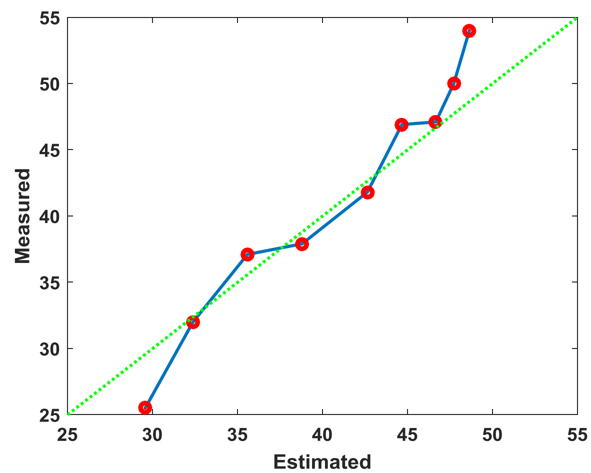

Figure 6. The estimated **vs**. the measured bed chair angle. The ideal result is shown by a green dotted line. Those red dots are from our experiments. All the units are in degree.

The bed point cloud represents the surface information of the mattress. To find out the problems, we check the side view to the bed point cloud at different angles. In figure 7, the mattress shape is changing in a very different way from the support bed base frames from which we get the measured ground truth value. This is reasonable since the top mattress is made with vivid springs and bottom support is from rigid metal frame.

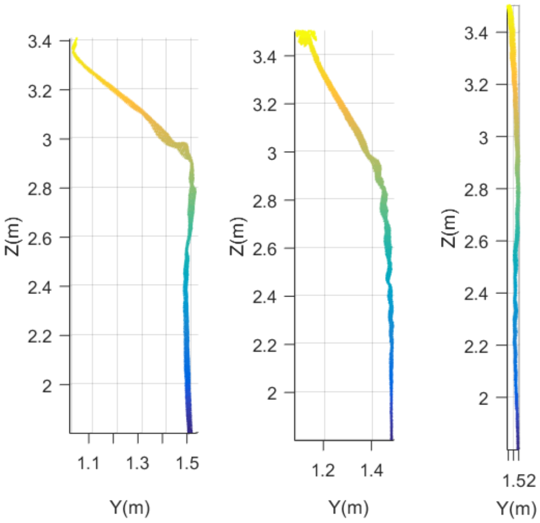

Figure 7. The side view to the bed point cloud at angle of 48.63^0, 29.56^0 and 0^0, respectively (from left to right).

For the same measured bed chair angle starting from a different initial position, the estimated angle may be not exactly the same each time because of the springs. Those results in figure 7 demonstrate that a larger bed chair angle will influence the mattress shape dramatically in the hinge part, which may impact the plane fitting result because of the fluffy shape on point cloud. If this part is smoothed, the estimated result matches well with the measured result (see the case when angle is zero in figure 7).

IV. Conclusions

The patient backrest angle in the hospital room is very important in reducing the risk of developing pneumonia during the hospital stay. Nowadays, the option on the outpatient treatment becomes more popular in saving money and time, which makes the hospitalized patient have more serious disease and vulnerable immune system than those in old times.

To prevent the patient acquiring HAIs, clinic staff needs to pay close attention to the hospital bed since patient spend majority of the time on hospital bed. A wrong bed chair elevation for a long time will increase the risks of getting new HAIs. Sometimes, patient may not realize that he or she is on a way of contracting infections due to the wrong backrest angle. It is also unrealistic for the clinic staff to sit beside the patient 24 hours a day. This paper proposed a feasible solution to solve this dilemma in hospital room. The system could estimate the bed chair angle from time to time and this result can be accessed by healthcare staff whenever it is necessary to understand the patient health situation and disease formation.

This proposed method has shown good performance in our preliminary experiments within a reasonable variance range. Our next step is to deploy this system in the real hospital room and let the system to help healthcare staff to monitoring bed angle in a more convenient way.

Acknowledgment

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