34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

Bed Detection For Monitoring System In Hospital Wards

Panachit Kittipanya-Ngam
Institute for Infocomm Research
1 Fusionopolis Way, 21-01
Connexis(South Tower)
Singapore, 138632
pngam@i2r.a-star.edu.sg

Ong Soh Guat
Institute for Infocomm Research
1 Fusionopolis Way, 21-01
Connexis(South Tower)
Singapore, 138632
sgong@i2r.a-star.edu.sg

Eng How Lung
Institute for Infocomm Research
1 Fusionopolis Way, 21-01
Connexis(South Tower)
Singapore, 138632
hleng@i2r.a-star.edu.sg

***Abstract*— Patient monitoring system has been providing a means for caregivers to regularly observe patients' condition in a multiple intensive care units from a single remote location in hospitals. In addition, the system may provide an addition layer of care, which includes software tools that support analysis of patients' vital signs, trends etc. To allow visual surveillance, cameras are installed in the patient wards. From the clinical observation, the key area in the hospital are around and on the bed as most of the activities take place and where patients spend most of their time. Therefore detecting the bed is the first basic task in studying and monitoring the patients' behavior. We have developed a novel technique in detecting the patient bed. This technique is based on Canny Edge detector and Hough Transformation. The algorithm is tested and the experimental results show that our proposed method can effectively locate the position of the patient bed.**

I. INTRODUCTION

Patient monitoring system has been one of the most important devices used in hospitals as it helps to monitor patients' conditions 24/7. Moreover, it helps to leverage the shortage of caregivers by providing a means for them to regularly observe patients in a multiple intensive care units from a single remote location. This system is intended to provide an addition layer of care, which includes the software tools that support analysis of patients values, vital signs, trends etc. Rawlese and Crockett [1] evaluated a monitoring system automatically monitoring and recording some vital measurements such as temperature, pulse rate and blood pressure. Ko et al.[2] studied the usefulness of MEDiSN, a wireless sensor network (WSN) designed to monitor vital signs continuously. Phyo Wai et al. [3] use multi-modal sensors to observe patient's context and activities around the bed such as sleeping postures and movement around the bed. Using surveillance cameras to monitor patient is still new in this field of application and need to be explored. For example, in [4], they have installed camera at intensive care units for observing agitation in the sedated patients. It is believed that it can provide other modes of information useful to the doctors and nurses and intelligent system with cameras allows computers to have 'vision'. In this project, we are studying the use of intelligent video analytic system in monitoring patients in hospital wards.

To allow visual surveillance, cameras of the system is installed in the patient wards. Cameras are mounted on the wall to capture the image of the single patient bed and we called this view as Bed View. Figure 1a is an example of Bed View image, it contains only one single bed. Bed View is useful as we can observe the patient with specific conditions.

(a) Bed View (b) Manually marked area of the patient bed

Fig. 1: *Sample of Bed View image and marked area.*

From clinical observation, the key area in the hospital are around and on the bed as most of the activities take place and where patients spend most of their time. Therefore detecting the bed is the first basic task in studying and monitoring the patients' behavior. Initially, we do manual marking at the area of the bed in our vision-based monitoring system. Figure 1b shows an example of a manually marked area of the patient bed. However we have found that the location of the patient bed changes over time. This could be due to many reasons, one of the reasons the bed has shifted could be when the doctors are doing regular check up or nurses are performing their cleaning duties on the patient. Also, it would be time consuming for the caregivers to constantly check and update the system the location of the bed. Thus it is important to implement a method which helps to detect the location of the bed automatically.

Most of the methods available only help in detecting rectangle or parallelogram [5] [6] [7] [8]. They are mostly used in detecting signboards [7] or car plates [9] [8]. For example, Rosito Jung and Schramm proposed a method to detect rectangle based on windowed Hough Transform [5]. The basic idea of the method is they make use of the geometric characteristics of the rectangle, such as four right angles, two pairs of equal length lines, etc. With these characteristics and the peaks found in Hough Space, a rectangle can be easily located. This method works well for detecting any quadrilateral with specific characteristics, such as rectangle and parallelogram which have 2 pairs of equal length lines and opposite angles are equal. However, this method is not feasible in detecting bed as the beds shown in the Bed View images are neither rectangle nor

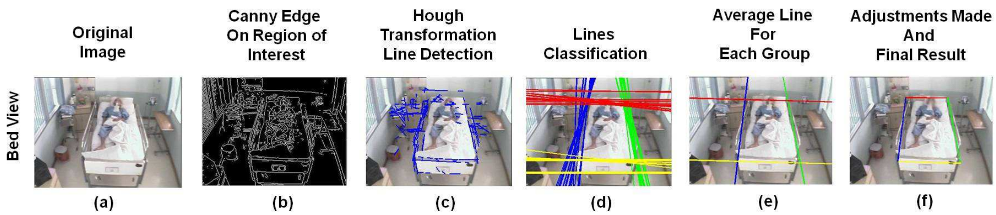


Fig. 2: *This figure shows the overview of the bed detection.*

	Upper Horizontal Line	Lower Horizontal Line	Left Vertical Line	Right Vertical Line
Angle of Gradient α	[0°, 45°] [135°, 180°]	[0°, 45°] [135°, 180°]	[45°, 135°]	[45°, 135°]
Midpoint (x_m, y_m)	$x \in [1, I_w]$ $y \in [1, I_h/2]$	$x \in [1, I_w]$ $y \in [I_h/2, I_h]$	$x \in [1, I_w/2]$ $y \in [1, I_h]$	$x \in [I_w, I_w/2]$ $y \in [1, I_h]$

TABLE I: *Conditions for Each Groups, where I_w and I_h are the width and height of the input image respectively.*

parallelogram. Beds appear in the Bed View image appear to be a quadrilateral, with the top bed border parallel to the bottom bed border line, and no specific corner angles (see Figure 1b). Hence we proposed a method which is able to detect the bed in the Bed View.

Knowing the location of the bed is useful in the patient monitoring system. Once the location of the bed is found, we can easily check if the patient is present on the bed. This can be done by detecting the head of the patient using the skin color present at the upper quarter of the detected bed. This information is extremely useful to the nurses on duty, for an absence of patient on bed for a period of time might suggest that the patient has encountered an accident such as fall in the toilet or other mishaps happen outside of the ward. Moreover, with the location of the bed found, bedsore can be prevented. When the patient stays in a single decubitus position for a long period of time, bedsore is likely to occur. The likelihood of bed sore occurring in the intensive care units patient is much higher, with 8% to 40% developing bedsores [10]. When the patient is detected to be presence on the bed, and yet unmoved for a period of time, the system will prompt the nurses on duty.

The paper is structured as follows: In Section II, we briefly explained Hough Transformation. Then we describe our proposed technique in details and how we implement our proposed technique in the patient monitoring system. Section III shows the experiment results. Finally both the discussion and conclusions are given in Section IV.

II. Edge Bed Detection

A. Hough Transformation

Hough Transformation is the linear transform for detecting linear lines and later use to detect arbitrary shapes such as rectangles, circles, parabolas, ellipses etc. Moreover, this method works on disconnected edges. Linear line in the image space can be described as $y = mx + c$, where x and y are the Cartesian coordinates, m is defined as the slope or gradient of the line, and c is the y-intercept. However, this expression raises a problem when handling vertical lines as both m and c are unbounded values. Thus, different set of parameters are used in Hough Transformation. These parameters are ρ and θ, where ρ represents the distance between the line and the origin, while θ is the angle of the vector from the origin to the closest point. With these parameters, a linear line can be expressed as

$$y = -(\frac{\cos\theta}{\sin\theta})x + (\frac{\rho}{\sin\theta}), \tag{1}$$

this can be rearranged to be

$$\rho = x\cos\theta + y\sin\theta, \tag{2}$$

with $\theta \in [0, \pi)$ and $\rho \in \mathbf{R}$. To find a straight line that fit a set of n data points $[(x_1, y_1), ..., (x_n, y_n)]$, first transform the data point (x_i, y_i) into the θ-ρ plane, where $i \in [1, n]$. For each data point, k different angles are plotted. Thus for (x_i, y_i) data point, will have $[(\theta_{i1}, \rho_{i1}), ..., (\theta_{ik}, \rho_{ik})]$. These points are then plotted into a curve in the Hough Space graph. These steps are repeated for all the data points. With all the points plot, the intersection of these curves will give a distance and angle. This distance and angle indicate the line which intersects the points being tested.

B. The Proposed Algorithm

The proposed method is based on Canny Edge detector [11] and Hough Transformation [12]. Figure 2 shows the process of our bed detection algorithm. Steps:

1) **Edge Detection**: Canny Edge detector is used for edge detection on the original input image. The advantage of using Canny Edge detector is it has better edge detection performance especially in noisy conditions [13].
2) **Hough Transformation**: After the edges are detected, next we use Classical Hough Transformation [12] to locate the straight lines.
3) **Classification of Lines**: After locating the straight lines using Hough Transformation, we classify these detected straight lines into 4 different groups, Upper Horizontal Lines (UHL), Lower Horizontal Lines (LHL), Right Vertical Lines (RVL), and Left Vertical Lines (LVL). We group these lines base on 2 factors,

the midpoint of the line, (x_m, y_m), and the angle of the gradient line, α, where $\alpha = \theta + 90°$. The conditions of α and (x_m, y_m) are listed in Table I.

4) **Extension of Lines**: After classifying the lines, the next step will be extension of each line in the 4 groups. To illustrate this, the two coordinates for lines in UHL and LHL should be $(1, y_1)$ and (I_w, y_2), and RVL and LVL should be $(x_1, 1)$ and (x_2, I_h), where y_1 and y_2 $\in [1, I_h]$, x_1 and $x_2 \in [1, I_w]$, I_h is the image height and I_w is the image width.
5) **Average Lines**: So after the extension of the lines is to find the average line for each group. This can be done by finding the average midpoint and average angle of gradient. Average midpoint for each group is defined as:

$$(\hat{x}, \hat{y}) = ((\sum_{i=1}^{n} x_i)/n, (\sum_{i=1}^{n} y_i)/n) \tag{3}$$

where n is the number of lines in each group, and (x_i, y_i) is the midpoint for each line in each group. As mention, the top bed border is parallel to the bottom bed border line, however, the right bed border might not be parallel to the left bed border. Thus to find the average angle of gradient for each group, it should be:

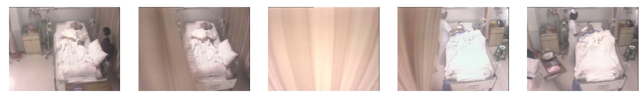
$$\hat{\alpha}_{uhl}, \hat{\alpha}_{lhl} = (\sum_{i=1}^{p+q} \alpha_i)/(p+q), \tag{4}$$

$$\hat{\alpha}_{lvl} = (\sum_{i=1}^{r} \alpha_i)/r, \tag{5}$$

$$\hat{\alpha}_{rvl} = (\sum_{i=1}^{s} \alpha_i)/s \tag{6}$$

where $\hat{\alpha}_{uhl}$, $\hat{\alpha}_{lhl}$, $\hat{\alpha}_{lvl}$, $\hat{\alpha}_{rvl}$ are the average angle of gradient for UHL, LHL, LVL and RVL respectively. p, q, r, s are the number of lines in UHL, LHL, LVL and RVL respectively and α_i is the angle of gradient for each line in each group.
6) **Adjustment of Average Lines**: The next stage will be adjusting the average line of each group. Two adjustments are made, the angle of gradient and the midpoint. First we have to computer the search space for the angle of gradient and the midpoints for each average line. This is done by 'tuning' the average line of each group. The search space for the angle of gradient is $\hat{\alpha} \pm 10°$, where $\hat{\alpha}$ refers to $\hat{\alpha}_{uhl}$, $\hat{\alpha}_{lhl}$, $\hat{\alpha}_{lvl}$ and $\hat{\alpha}_{rvl}$. The search space for the midpoint x and y are $\hat{x} \pm 10$ pixel and $\hat{y} \pm 10$ pixel respectively. However, the 'tuning' of midpoint x is done only for the average lines of both the LVL and the RVL, and the 'tuning' of midpoint y is done only for the average lines of both the UHL and the LHL. For each average line, they have their 'tuning' lines, we select the line with the maximum edges fall on the 'tuning' line.
7) **Adjustment of the UHL**: For the bed view, the head of the patient will not be always inside the bed boundary, we have to correct boundary such that the head will be inside the boundary. This is an important step as after bed detection, we can check the presence of a patient by using the skin color of the head. We need to check only the adjusted line for the UHL. To check if the head is inside the bed boundary, we find the intensity of the pixel falls on the upper horizontal line. If the standard deviation of the intensity is more than a threshold, then we conclude head is not inside the bed boundary. We shall move the horizontal line upwards such that the standard deviation of the intensity is less than threshold.

C. Bed Detection in Patient Monitoring System



(a) (b) (c) (d) (e)

Fig. 3: *3a: Curtain is not drawn yet. 3b: Nurse is drawing the curtain. 3c: Curtain is drawn. 3d: Nurse is un-drawing the curtain. 3e: Bed is shifted after nurses perform cleaning duties.*

In order to capture the activities of the patient take place on the bed, together with the nurses, we have considered 2 different angles which the cameras can be mounted. The first way is to mount the camera on the ceiling above the patient bed. However, at this angle, the caregivers are concerned on the patients privacy. Taking into consideration of not intruding into patient's privacy, we have decided to mount the camera outside the curtain rail of the patient bed. This gives both the patients and caregivers a choice to draw the curtain whenever they want.

Bed detection algorithm is implemented in the patient monitoring system. However, we do not apply bed detection for every frame as there is not much changes in the patient's bed position from frame to frame. In addition, bed detection is de-activated once the curtain is drawn. Usually, doctors and nurses will draw the curtain when they do regular checkup or perform cleaning duties. We realize the bed is usually shifted after these. Thus it is important to activate the bed detection once the curtain is un-drawn. Figure 3 shows some of the image sequences before and after the curtain is drawn. With these, we decided to apply bed detection algorithm in the following conditions:

1) Bed detection is done for every 10 minutes. However, we shall only update the bed position every hour. This is done by averaging the positions collected every 10 minutes.
2) Bed detection is done if the curtain is detected to be drawn at the previous frame. This is because the position of the bed is likely to change.

III. EXPERIMENTAL RESULTS

A. Test Data

Using angle of view suggested in Section II-C, we have collected 10 different datasets over 6 days from two different patient wards. Each dataset contains around 388000 images. These datasets include bed which either with the present of a patient or without the present of a patient, and with either the present of visitors, caregivers or patient himself only. To test the proposed bed detection algorithm, we have randomly selected 100 images from each dataset. Thus we have 1000 test images from 10 different datasets. The size of images tested is 240 pixel by 320 pixel. For these 1000 images, we have manually marked the area of the bed to get the 4 marked coordinates of the bed.

B. Results

Figure 4 shows some of the detection results when we applied our algorithm. In Figure 4, the red lines indicate the manually marked area of the bed, and the blue lines indicates the bed detection result. To check the accuracy of our algorithm, we measure the distance between the detected coordinate and the marked coordinate of the bed, and take average of the 4 coordinate‘s distances. Table II shows the average coordinates distance of each dataset. The average distance for the 10 datasets is 14.329 pixel with a standard deviation of 4.945 pixel.

The average coordinates distance of Dataset 1 is higher, it contains images whereby nurses are performing cleaning duties (see Figure 4q - Figure 4s) or patient relatives are standing close to the bed (see Figure 4t - Figure 4x), thus making the proposed algorithm unable to detect the bed edges. The time required to detect the location of the bed for each frame is around 15.375 milliseconds.

Dataset	Average Distance Coordinates (pixel)	Dataset	Average Distance Coordinates (pixel)
1	23.015	6	9.822
2	22.457	7	20.065
3	15.232	8	10.284
4	10.354	9	13.329
5	15.514	10	9.412

TABLE II: *The table shows the average distance of each dataset.*

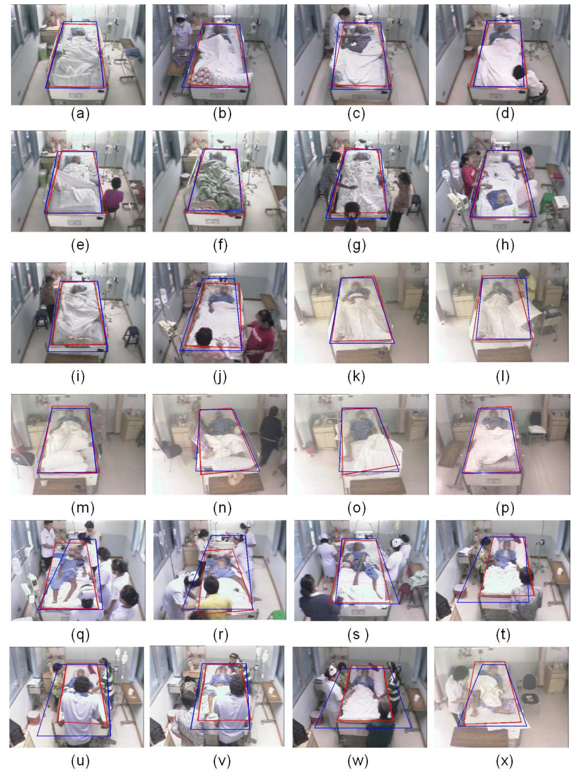


Fig. 4: *This figure shows the performance of our bed detection. The blue marking indicates the bed detection result from our proposed algorithm. The red lines indicate the marking done manually.*

IV. DISCUSSION AND CONCLUSIONS

Detecting the bed is the first basic task in studying and monitoring the patients behavior. We have proposed a real-time method to detect the location of the patients bed in the ward. We have tested our approach on the Bed View images on 10 different datasets. However, we realized that nurses and visitors might be affecting the results of the bed detection. This happens only when they are standing at the edge of the bed. In conclusion, we have demonstrated an effective way to locate the position of the patient bed.

REFERENCES

[1] J. M. Rawless and G. Crockett, “Automation on a general medical ward: Monitron system of patient monitoring,” *British Medical J.*, vol. 3, pp. 707 – 711, Sept. 1969.

[2] J. Ko, T. Gao, R. Rothman, and A. Terzis., “Wireless sensing systems in clinical environments: Improving the efficiency of the patient monitoring process,” *Engineering in Medicine and Biology Magazine*, vol. 29, pp. 103 – 109, Apr. 2010.

[3] P. W. A. Aung, F. Foo, H. Weimin, B. Jit, J. Phua, L. Koujuch, and H. Chi-Chun, “Evaluation and analysis of multimodal sensors for developing in and around the bed patient monitoring system,” *Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conf. of the IEEE*, pp. 2159 – 2162, Sept. 2009.

[4] J. G. Chasea, F. Agogueb, C. Starfingera, Z. Lama, G. M. Shawc, A. D. Rudgea, and H. Sirisena, “Quantifying agitation in sedated icu patients using digital imaging,” *Computer Methods and Programs in Biomedicine*, vol. 76, pp. 131 – 141, Nov. 2004.

[5] C. Jung and R. Schramm, “Rectangle detection based on a windowed hough transform,” *Computer Graphics and Image Processing, 17th Brazilian Symposium*, pp. 113 – 120, Oct. 2004.

[6] F. Rajesh, “Rectangle shape recognition using one-dimensional array,” *Computational Intelligence and Computing Research (ICCIC), 2010 IEEE International Conf.*, pp. 1 – 4, Dec. 2010.

[7] A. Tam, H. Shen, J. Liu, and X. Tang, “Quadrilateral signboard detection and text extraction,” *International Conf. on Imaging Science Systems and Technology*, pp. 708 – 713, 2003.

[8] T. D. Duan, D. A. Duc, and T. L. H. Du, “Combining hough transform and contour algorithm for detecting vehicles’ license-plates,” *Intelligent Multimedia, Video and Speech Processing*, pp. 747 – 750, Oct. 2004.

[9] V. Kamat and S. Ganesan, “An efficient implementation of the hough transform for detecting vehicle license plates using dsp’s,” *Real-Time Technology and Applications Symposium*, pp. 58 – 59, May 1995.

[10] J. Cuddigan, D. R. Berlowitz, and E. A. Ayello, “Pressure ulcers in america: prevalence, incidence, and implications for the future. an executive summary of the national pressure ulcer advisory panel monograph,” *Advances in Skin and Wound Care: The J. for Prevention and Healing*, vol. 14, pp. 208–215, Aug. 2001.

[11] J. Canny, “A computational approach to edge detection,” *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 8, June 1986.

[12] P. Hough, “Method and means for recognizing complex patterns,” 1962.

[13] M. Juneja and P. S. Sandhu, “Performance evaluation of edge detection techniques for images in spatial domain,” *International J. of Computer Theory and Engineering*, vol. 1, no. 5, pp. 614 – 621, 2009.