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An ID and Position Recognition Method employing Camera Motion Blur for Modulated LED Tube Lights

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Abstract

In this paper, we present an image-based 3D positioning method by using produced motion blur for a novel camera-based indoor navigation system. This system, avoiding adopting any expensive equipment, could provide exact 3D location and orientation for mobile users. High-intensity LED tube, which is expected to be the next generation of illumination source, is used as optical marker in this system. LED tubes are modulated to transmit ID information and the message is received by handy terminal which is equipped with one normal camera. The exposure time of a common camera is usually longer than flicker period of LED lamps, and this makes difficulties for ID recognition. We study a method to solve this problem. If camera is shaken by user's hand while the period of exposure, on captured image a streaked pattern would be produced and that could be used for retrieving ID number. Result of experiment shows this method is feasible.

1. Introduction

Location awareness is a key aspect for ubiquitous computing applications on mobile terminal today. In outdoor environment Global Positioning System (GPS) is already maturely developed and widely used. However, GPS relies on lines of sight to GPS satellites, and in huge building or underground city the signal is usually blocked. In order to provide indoor positioning service, various technologies employing active base stations [1], including ultrasonic, Bluetooth and magnetic ways, have been proposed. But they all require a network of electric infrastructure, which means high cost of installation and maintenance. These problems prevent the deployment of these systems in large scale.

Positioning method based on visual information could solve these problems to some extent. Some researches decide the position by tracing natural features. Miyashita et al. presented a PC-based museum guide system using natural-feature tracking [2]. However, these systems usually exceed the processing capability of current handy terminal such as the smart phone. Approaches based on artificial marker [3] have also been applied for indoor localization. These systems are robust and the computation consumption is low, but the markers which are placed everywhere would be thought visually obtrusive in interior scene. Mulloni et al. [4] arrange the ID data along the border of a square to make it unnoted, and the remaining part of the square could contain arbitrary content.

We presented a visual positioning system using existing illumination infrastructure, which has been installed at of a building, as the optical marker with known position. This kind of system could be expected be very cheap to provide service in wide indoor environment. Makino et al. have introduced several walking assist systems [5] for visually impaired, and these systems employed fluorescent lights as information transmitter.

In our system LED tube lights are used to transmit message. These years, white LED for illumination has made great developments and it is expected to take place of conventional illumination instrument in near future. LED tube lights, which could directly take advantage of the existing infrastructure for tranditional fluorescent, are especially paid more attention. One important characteristic of LEDs is that they are capable of switching on and off at a very fast rate. In our system, LED tubes are spatially modulated to transmit ID information which is received by a normal camera. Finally the accurate 3D position and orientation of terminal is estimated and this system could provide users assistance such as the guidance to certain place.

In previous work, in order to capture the pattern of the tube which is switching at a high speed, we set exposure time of camera very short (about 1~2ms). However, usually the cameras equipped on smart phone do not provide such adjustment. In this paper we present a method to achieve ID recognition with normal exposure time by producing motion blur.

This paper is organized as follows. In Sec. 2, our system is briefly introduced. In Sec. 3, method using motion blur for ID recognition and position estimation is described. Sec. 4 denotes the result of experiment. And finally, the conclusion is given in Sec. 5.

2. Proposed System

This proposed system assumes that the illumination source is LED tube. Compared to point light source, line source provides more inherent spatial feature, which is helpful for location estimation. The LED tubes are modulated in the way of spatial coding so that there is no requirement for the shutter rate of camera. Each LED tube is partitioned by several separate LED lamps, and if at an instance the on/off of LED lamps are arranged in a special pattern, the whole tube could be used to transmit a specific message.

We make the LED tube switching quickly between two states: positive pattern and negative pattern. And either one is the complement of the other. The circuit of LED tube in this system is fairly simple and without any microcontroller. The flickering effect is directly generated by pulses of AC power source, and all of the LED lamps appear to be lighting at the same brightness for human eyes due to the high frequency. The message is encoded in the way of Manchester coding, namely that two consecutive lamps are used to express one digit of information. This method could provide a balance of light distribution between two states and robust ID recognition. This method of ID modulation is showed as Table 1.

Table 1. Example of ID modulation.
(○ on, ● off)

ID code	0	1	1	0…
Positive pattern	●○	○●	○●	●○…
Negative pattern	○●	●○	●○	○●…

If one individual optical beacon consists of only one LED tube, an approximate estimation of both location and orientation is expectable. In many cases, a rough result with the error about 2~3 meters is enough for practical application. However, with the purpose of accurate location and orientation estimation, we employ the unit of two parallel tubes in experiment. The scenario of an expected application of our system is shown as Fig. 1.

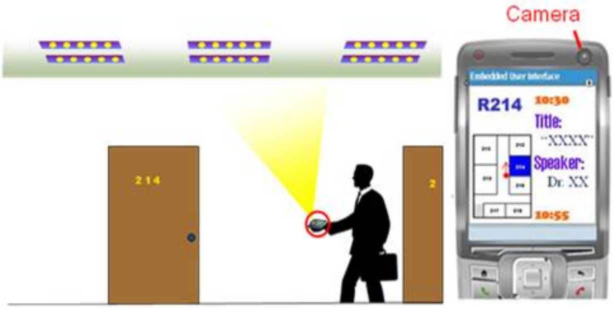

Fig. 1 Indoor navigation.

A digital camera, which has become an essential part of cell phone today, is used as receiver. The exposure time of camera is set very short to capture the pattern and the ID number of the unit of tubes is retrieved (Fig. 2). The positions of beacons in world have been stored in database with the index of ID number. With the positions of four corners of optical beacon in image, the estimation of camera location respect to tubes becomes a Perspective-4-Point problem and it has one unique solution and the position and orientation of handy terminal can be obtained. The amount of available unique IDs would be more than one million. This means the proposed system could meet the requirement of application in a huge building or even a whole campus.

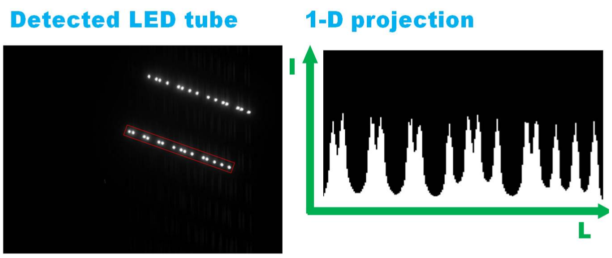

Fig. 2 Captured image and intensity profile along tubes.

3. ID Recognition using motion blur

3.1. Motion-blurred image

As mentioned before, in our previous work the exposure time of camera was set very short. Consequently, two problems lie in this approach. First, not all of the cameras on mobile phone are available for the adjustment of exposure time. Second, there is a possibility that the timing of exposure always falls at the moment when the lamps turn dim, and the ID recognition would keep on failing for a while.

If the camera is moving rapidly in a proper direction while the exposure, streaked pattern, which could be used for ID recognition, is displayed on image (Fig. 3).

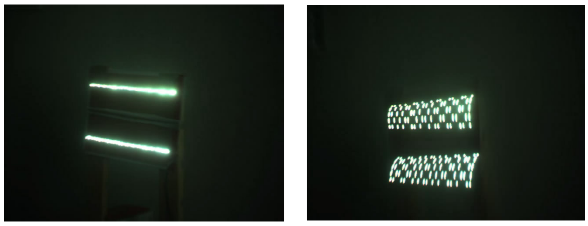

Fig. 3 Still image and motion-blurred image.

3.2. 1-D Template Matching for ID recognition

At first, the approach for retrieving ID number from 1-dimentional signal is studied. It has been mentioned above that LED lamps are divided into several pairs and the states of two lamps forming one pair must be different (Manchester coding). Therefore, a template, which consists of several segments corresponding to these pairs of lamps, is used for matching the regions of lamps. The processing is briefly illustrated as Fig. 4.

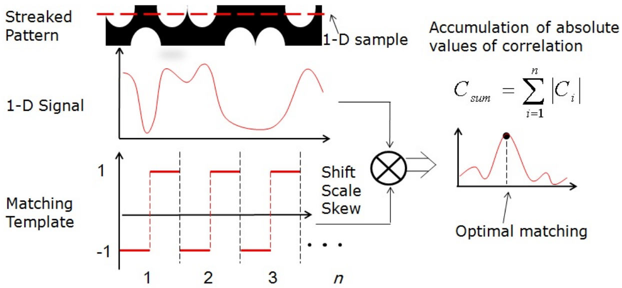

Fig. 4 Template matching.

In our experimental setup, the amount of segments in one template is 15. For each segment, the value of right half part is 1 and the value of left half part is -1. When the template is placed on a 1-D signal, all of the correlation values between each segment and the signal region covered by this segment are calculated. If the matching is accurate, the absolute value of correlation would be obviously larger than other cases. The next operation is accumulating absolute values of all correlation results. The accumulation result will be used to evaluate the accordance of matching:

$$C_{sum} = \sum_{i=1}^{n} |C_i| \tag{1}$$

In order to find out the optimal matching, the offset and shape of template will be varied with three parameters: scale, shift and skew, and all of the results with unique set of parameters within certain range are calculated. And we assume that the set of parameters which gets the largest value of C_{sum} is the optimal matching.

3.3. ID recognition on image

We define an evaluation value to judge the confidence that the region coverd by template is indeed the ID pattern or not after the optimal matching is decided. We name this evalutation value to be *E*. The value of *E* is expressed as Eqt. (2). If *E* is close to 1, result is likely to be a real ID.

$$E = 1 - \frac{Stdv\{|C_n|\}}{Ave\{|C_n|\}} \quad (2)$$

An experiment is carried to decide the threshold value of *E*. Videos including motion-blurred frames are used as sample data. 1-D decoding was operated at multiple positions and directions for each frame. The range of positions and directions has been roughly constrained by analyzing the contour of bright area. The false examples and the true examples are respectively counted, and the distribution of *E* is shown as Fig. 5.

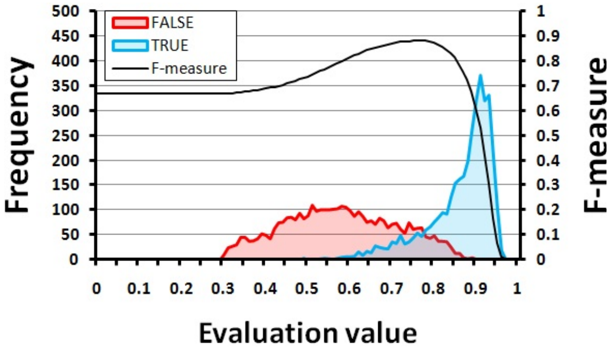

Fig. 5 Distribution of *E* value.

It could be seen the evaluation value corresponding to peak value of F-measure is close to 0.8. Therefore, we make 0.8 the threshold for a primary judgment. Of all the examples whose *E* value is greater than threshold value, percentage of true examples is 94.3%. Fig. 6 shows the result of a sparse scanning with the threshold judging.

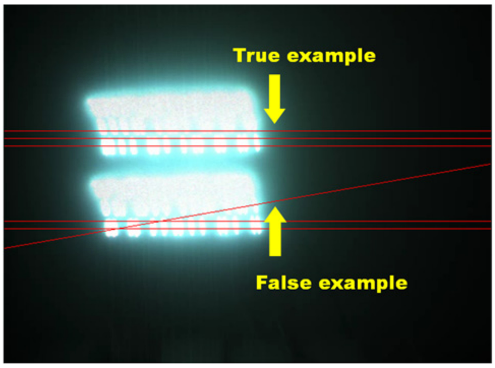

Fig. 6 Result of sparse scanning.

After further judgment such as error code check, direction check by referring to the other tube, and occurring frequency, it is easy to eliminate the false results. In experiment, it is achieved that retrieving right ID from more than 80% frames of a well motion-blurred video (totally 400 frames) with a false acceptance rate of zero.

3.4. Location estimation with motion-blurred image

Finally, we attempt to perform positioning with one motion-blurred frame. Due to the phenomena of “blooming”, the image expresses massive overexposed regions corresponding to LED tubes if the camera keeps still. With such frames, plenty of error would be induced in the result of locating endpoints. Oppositely, if we could operate the location estimation on a motion-blurred frame, it could be expected to effectively reduce error. For this purpose, tubes should be located on frame at a specific instance. However, within the period of either positive or negative pulse, locating the tubes at certain instance is difficult. We could solve this problem by extract the line between adjacent positive area and negative area, and the instance is just while the current direction changes.

The possible pairs of two lines respectively corresponding to two tubes are used to estimate the position of terminal. Of course, some of the combinations are not correct because within the exposure period, the current switch either from positive to negative or opposite direction occurs several times. As a Perspective-4-Point problem, the constraint conditions provided by 4 reference points are redundant. Namely, we could use the back projection error to judge the combination of two lines is correct or not. In our preliminary experiment, when the combination is correct, the back projection error was always less than 3 pixels.

4. Experiments

The parameters of prototype system for experiment are shown in Table 2.

Table 2. Parameters of prototype system

Unit of LED tubes	
Length of tube	275 mm
Distance between two tubes	152 mm
Amount of lamps per tube	28
Frequency of flicker (AC source)	60 Hz
Camera	
Field of view	30 deg
Resolution	640×480
Shutter rate	30 Hz
Exposure time	33 ms

In experiment, the prototype unit of LED tubes was mounted on the ceiling. A web camera, whose size and user experience for shaking is close to a mobile phone, is hold by hand and the distance from camera to ceiling is about 1m.

4.1. Relation of blur direction and recognition result

In experiment, the camera was shaken at various directions. Average of evaluation value and the proportion of true examples whose E value is over threshold are recorded according to the classification about the angle between the blur direction and direction along the tube. The result is shown in Fig. 7.

From the result, it can be seen that the average of evaluation value and recognition rate generally get smaller as the angle decreases. And around the angle of

45 degree, there is a quick drop of the recognition rate. The reason is that if the angle is sharp, during the exposure time, on image the position of certain lamp at certain moment would be superposed by another lamp at other moment. Therefore, ID recognition using the finally produced image gets more difficult. It could be expected that the range of available angle is between 50 degree and 90 degree.

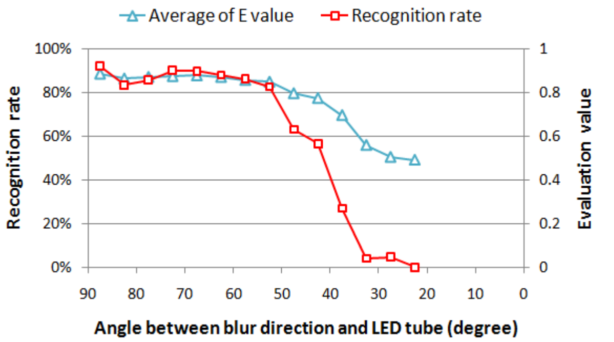

Fig. 7 Relation of blur direction and recognition result.

4.2. Relation of blur length and recognition result

In the next experiment, the camera was shaken with various speeds and the length of motion blur was changed. We define the length of motion blur to be the width of streaked pattern area due to one pulse of AC source. Recognition results are recorded according to the classification about the length of blur. The angle between motion blur and LED tube is close to 90 degree, and the length of LED tube on image is about 150 pixels. Result is shown as Fig. 8.

From the experiment result, it can be seen that the average of evaluation value and recognition rate generally get larger as the length of blur increases. The reason is that when the moving speed of camera is slow, image exposes too much at the position where the lamps are and the saturated areas get massive. Therefore, the dim part of pattern would be influenced and the difficulty of ID recognition increases.

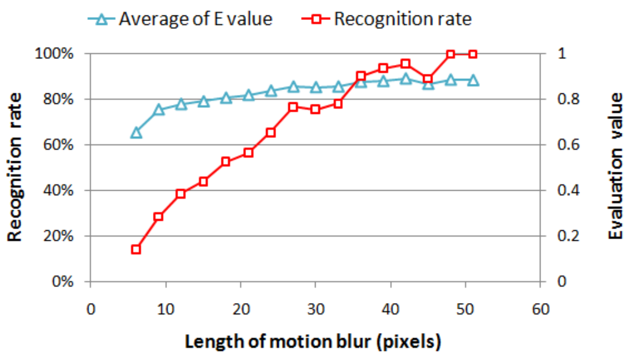

Fig. 8 Relation of blur length and recognition result.

4.3. Position tracking

The performance of the position estimation with motion-blurred image was experimented. The camera was held by user's hand and moved in a circular trajectory below a ceiling unit of tubes. During the moving, user kept on shaking camera in a proper direction to produce motion blur. A receiver of electromagnetic motion tracking system FASTRAK was attached on camera, and the tracking results of FASTRAK are used as the reference of true positions. The distance from camera to the ceiling unit is about 1m. The tracking result is shown in Fig. 9.

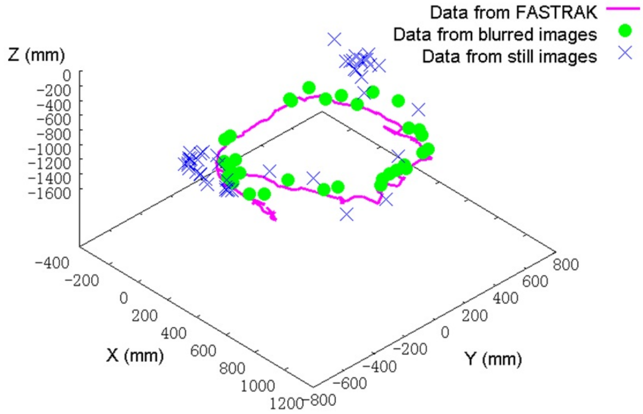

Fig. 9 Result of position estimation.

Result shows that position estimation results from motion-blurred images have quite higher precision than results from still images. It is expectable that the maximal error would be less than 10cm with motion-blurred images in practical situation.

In the experiment, the effective measurement range with our small-scale model is about 3m×2m. It is possible to cover whole room without blind area when this system is applied to a real room in a practical case.

5. Conclusion

A 3D decoding and positioning method for LED tube utilizing motion blur is presented. This approach expands the LED ID marker system to both short and long exposure time cameras. With the test model, experimental result indicated that this approach is effective.

Our proposed system could provide exact indoor positioning service without any special and expensive equipment. What is more, this system is cheap to be installed in a wide area, and there is almost no maintenance cost. Only a normal camera which is very common on mobile phone today is required as the sensor, so the implement of this system in near future is expectable. We believe it is a promising system.

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