WEBCAM-BASED LASER DOT DETECTION TECHNIQUE IN COMPUTER REMOTE CONTROL

HOANG-AN LE, MINH-THONG DOAN, MINH-TRIET TRAN

ABSTRACT

In this paper, the authors propose a method to detect the laser dot in an interactive system using laser pointers. The method is designed for presenters who need to interact with the computer during the presentation by using the laser pointer. The detection technique is developed by using a camera to capture the presentation screen and processing every frames transferred to the computer. This paper focuses on the detection and tracking of laser dots, based on their characteristics to distinguish a laser dot from other areas on the captured frames. Experimental results showed that the proposed method could reduce the rate of misdetection by light noises of a factor of 10 and achieve an average accuracy of 82% of detection in normal presentation environments. The results point out that the better way to describe the laser dots' features based on visual concept is to use the HSI color space instead of the normal RGB space.

Keywords. laser pointer; laser dot/spot; laser pointer interaction; control; mouse; computer screen/display.

1. INTRODUCTION

Laser pointer is a popular device in video-projection-based conferences and classes, where presenters may move freely around the stage without being constrained by the reach to the computer. A laser pointer helps a presenter in interacting with a projection screen such as highlighting or pointing at an object on the screen despite the place of the presenter.

A regular computer equipped with a normal keyboard and mouse usually limits presenters' mobility while other remoting devices such as wireless mice, or slideshow controllers are not popular because of the high cost, the limitation in manipulation (wireless mice require horizontal surfaces to be used) or limitation in use (slideshow controller is dedicated for PowerPointer® presentation only and not suitable for general use). Taking the advantages of the low cost and the common use of laser pointers in presentation, the authors introduce an interactive system that uses a laser pointer to control a mouse cursor.

The problem described in this article belongs to the Human-Computer Interaction (HCI) technology, which is "a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of phenomena surrounding them" [2]. In HCI technology interacting methods which define the way people can use a computer have developed rapidly [3] and achieved significant results such as the mouse, windows and text editing, etc. [4]. However, not just stop at some certain techniques, people try always to find new techniques to make the interaction easier and more appropriate in various circumstances, such as to use laser pointer, eyes' movement, hand or face gestures recognition in remoting control computers [5]. However, for use in normal schools and classes, especially in Vietnam where expensive technically special devices such as electrodes (for eye-controlling [5]) or high-resolution webcam (to detect finger movements or face gestures at a distance) or Palm or PocketPC (to do the sematic snarfing technique [6]) is inaccessible, these solutions are not suitable.

For the design, the authors propose using a front-screen webcam to track the movement of the laser dot on the projection screen. Each frames extracted from the captured video stream is scanned and searched for the laser dot before transferring information to the interactive system where the laser dot's position and behaviors is translated into mouse cursor position and mouse signal. The approach using webcam or video camera is used because it relatively simple to implement and popular to computer users [1]. In addition, the setup suggested is also very common in several projects on controlling computers using laser dot tracking techniques [1, 7 - 12].

This article concentrates on the laser dot detection technique, which is to find an appropriate and effective way to detect the laser dot in the normal presentation environment; However, in applying the detection technique into real-time tracking, the system requires an implementation of screen calibration. Instead of waiting for users to calibrate the screen, the authors suggest a system that supports the automatic calibration based on the homography generation technique [10, 13]. The system uses the local feature method SURF (speeded-up robust features) [14] to find some interest points before applying the RANSAC paradigm (Random Sample Consensus) to automatically generate the homography matrix.

2. BACKGROUND AND RELATED WORKS

2.1. Laser dot detection technique

Several articles have come up with the design and solution for the detection technique. [7] suggests an image processing phase with three sub-phases to detect the laser dot with the accuracy of 50%. The detecting technique suggested by several articles is to test the brightness and color value of laser dot pixels. Eckert and Moore [9] checks for pixels having brightness and RGB color values greater than a certain threshold which is determined initially and depends on the presentation environment; Olsen and Nielsen [10] detects the laser dot by tracking the brightest red spot on the screen, while Kovárová, Mészáros and Zelman [12] searches in four successive frames for 5-pixel area with the biggest difference and intensity above the exact threshold. To increase the reliability and accuracy of the detection technique, a filter is used to get rid of unnecessary areas on an image so that the laser dot is distinguished and observable by the camera: the filter ND-4 or ND-8 helps decrease the receiving light but have to be used with highly intensity laser pointers15]; the color filter filters out all the colors except the red one [1, 16]; the diffractive optical element (DOE) filter makes the image blurred except for the laser dot [1].

However, Brad A. Myers et al.'s performance test states that actually, the laser pointer interaction is unsteady, error-prone and slow [17]. To overcome those limitations, a fast and reliable algorithm with 5 phases [18] which can detect the laser dot in 100% frames is developed for laser dots real-time tracking. To focus on practical details, Ahlborn et al. [19] provides a design and effective algorithm which can be used in several different light-condition environment by using background removal techniques, manipulating the brightness threshold as a variable and using an detection algorithm similar to [20].

2.2. Screen calibration technique

The screen calibration is one of the problems to be concerned in computer interaction systems. This is because an image captured usually gets the barrel distortion effect13] or the keystone effect. To deal with the issues, [19] suggests using the homography generation.

Based on the homography theory, the mapping between the screen's image on the wall and the real screen requires a fundamental (transformation) matrix [19]. The system proposed in this article can be used to automatically calculate the fundamental matrix using RANSAC (Random Sample Consensus) paradigm [21]. This paradigm helps estimate the homography matrix using a subset chosen randomly from a set of key points. One of the most commonly used methods to generate key points from an image is SIFT (scale invariant feature transform) which was proposed by Lowe in 1999 22]. However, with the purpose of applying in real-time detection, the authors use the new method to select local features, namely SURF (speeded-up robust features) [14], which focuses on scale and in-plane rotation invariant detectors and descriptors.

3. EXPERIMENTS ON CHARACTERISTICS OF LASER DOTS

3.1. Experiment 1: Brightness of Laser Dots

Observation of laser dots in some photographs and in [10, 12] shows that because of light saturation a laser dot does not appear in a photo as just a red spot but with a white area in the center. This white area is called saturation area which has very high brightness. Based on this phenomenon, this section is used to test the brightness of laser dot's saturation area to see if it can be used to characterize a laser dot.

The experiment uses 100 photographs taken laser dots in various kinds of condition. For each photograph, the graphic editing program Microsoft Paint© is used to crop out saturation areas to separate files. Because a photograph is rectangular and saturation areas, however, are not in regular shapes the authors can only crop out the circumscribed rectangle of the needed area. The unexpected pixels in the newly-created images and the hole created from the cropping process are then marked by a certain color, a black color with value RGB (0, 0, 0) as chosen. In this manner, they can be easily recognized when the authors have a program scan through the photograph. The pixels' brightness value is measured using the formula [23]:

$$Y = 0.299R + 0.587G + 0.114B \quad (1)$$

Figure 1 shows the result of the experiment which has the average value of 233.11 and the standard deviation of 33.20. The result in combination the value table shows that there are 90.57% of pixels measured having the value in the range from 200 to 255. From this result the authors defines a brightness threshold of 200 and track for all the pixels that have brightness above that threshold. This approach is similar with the one in [9, 10, 12] except for the fact that these articles search for the red pixels not white pixels.

To test the result's reliability, the authors examine the brightness of pixels in non-laser dot areas. The data for this test are the photographs with laser dot picked out and black area replaced created from the previous test. The result in Figure 2 shows that there are 96.52% pixels in these non-laser dot areas having the brightness value below the threshold of 200.

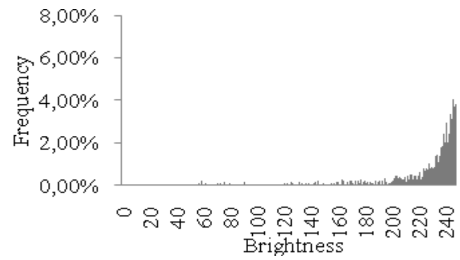

Figure 1. The histogram of laser dot areas' brightness

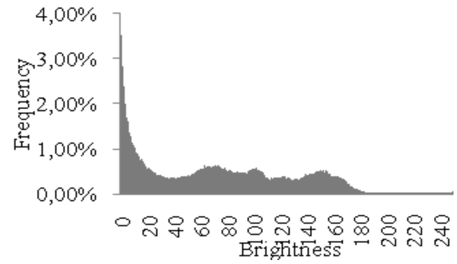

Figure 2. Histogram of non-laser dot area's brightness

3.2. Experiment 2: Color of Laser Dots

It is from the experiment 1 that the way using the brightness threshold to detect the laser dot is insufficient because there are several areas having the same brightness. In this experiment, the authors try to take advantage of the noticeable feature of a laser dot that is the highly bright red luminous area, the red area surrounding the saturation area.

Because this description is human interpretation and may not be true in machine's perspective, the RGB color model which is popular and convenient in image processing [24] may not be suitable. The HSI model, which "corresponds closely with the way human describe and interpret colors" [24] is used to describe laser dots characteristic. The data for this test is converted from RGB value to HSI value, using the formulae [24].

$$\theta = \cos^{-1}\left(\frac{0.5(R-G)+(R-B)}{\sqrt{(R-G)^2+(R-B)(G-B)}} \right) \quad (2)$$

$$H = \begin{cases} \theta, & if\ B \le G \\ 360-\theta, & if\ B > G \end{cases} \quad (3) \qquad S = 1 - \frac{3}{R+G+B}\left[\min(R,G,B)\right] \quad (4) \qquad I = \frac{R+G+B}{3} \quad (5)$$

The value of H calculated from (3) which is originally in the range of [0, 360] is converted to the range of [-180, 180] for convenient purpose in data analysis. The result is shown in Figure 3a with average value of -4.23 and the standard deviation of 35.07. The range [-39, 31] indicates that most of the data (78% according to the value table) is in red color.

The saturation test's result provides the average value of 33.82 and the standard deviation of 31.51. This distribution in comparison with the range's wide of 100 is so large that the result cannot be used in the detecting process. The intensity component reflects the brightness of tested pixels which has the average value and the standard deviation of 160.32 and 40.19, respectively. The numbers in combination with Figure 3b tell that the brightness of the luminous area is not really too high; however, when the environmental light is high or the pixels are near the center, i.e. the saturation area, the intensity those pixels becomes nearly 200 which is the brightness threshold derived from the experiment 1. These results explain the detection technique that searches for the high intensity red areas used by the articles [10, 12]. To describe the laser dot, the authors choose the upper half for the range of intensity that is from 160 to 200.

From the results derived, to characterize the laser dot including the red and the brightness attribute, the authors choose HSI model with hue in the range [-39, 31] and intensity in the range [160, 200].

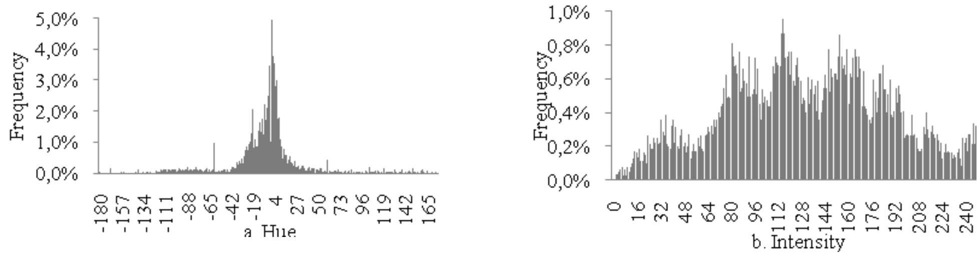

Figure 3. Histogram of HSI value of laser dots' pixels

3.3. Experiment 3: Laser Dot Detection Accuracy

In this section, the authors try to combine the result from experiment 1 and 2 to develop a technique that helps detect a laser point in an image and measure the accuracy of that technique. It is from previous experiment that the saturation area and the luminous area are treated as if they are different parts, but in fact the white area is the luminous one with colors saturated. So, in this experiment, the authors suggest merging the two results by developing a technique that looks for pixels satisfying both the brightness threshold and the hue value constraint. However, to have several results to compare, the author do not use only the results from previous experiments but test several other values around those numbers.

Let H and H_a be the standard deviation and average value of hue, which from experiment 2 is 35 and -4 respectively. The hue constraint is the range $[H_a - H, H_a + H]$ which the authors try to change by increasing or decreasing H. For a fix value of H, the value of the brightness threshold B is changed and the numbers of pixels is counted. Within the range of 5 pixels from the marked center, any detected pixel is considered true positive and any rejected pixel is counted as false negative. In the rest of the photograph, every detected pixel is false positive and the others are true negative. The values of H and B are chosen based on the result from experiment 1 and 2. With B starting from 200 and H starting form 35, the authors increase or decrease H by 10 units and B by 5 units. For each case the number of pixels is counted and classify into the 4 categories, the true positive, true negative, false positive and false negative category. The results are shown in Figure 4, Figure 5 and Figure 6.

At first glimpse, when B increases or H decreases, the number of true positive, false positive decreases while the number of false negative increases. It is noticeable that the changes of the true positive and false negative are simply gradual but the change of the false positive is more complicated. The graphs decrease more steeply when reaching the value of 205 then decrease gradually. At this value, it is shown in both three graphs that the number of pixels changes slowly when H changes; the markers at each value of B get nearer to each other when B becomes larger.

So, the authors try to increase B to reduce the false positive although this may decreases the true positive also. After the value of 205, the amount of false positive decreases a little regardless of H while the number of true positive decreasing rapidly. This makes the authors stop B at the value of 205. For hue value, when B is 205, H increasing makes the true positive increases significantly while the false positive increases little. In conclusion, the values of H and B are changed to 205 and 75 to increase the detection accuracy.

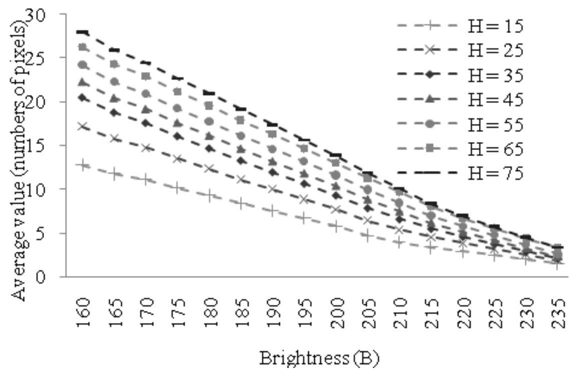

Figure 4. Numbers of true positive pixels according brightness and hue

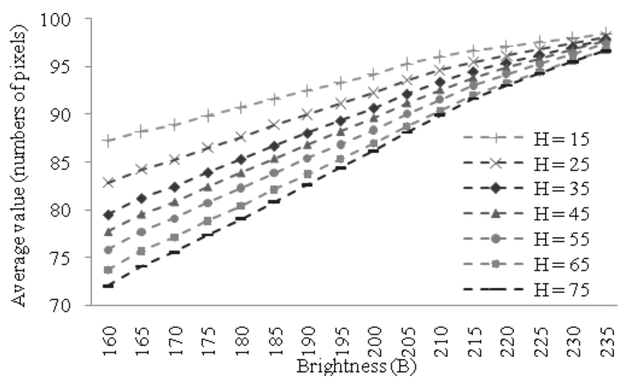

Figure 5. Numbers of false negative pixels according to brightness and hue

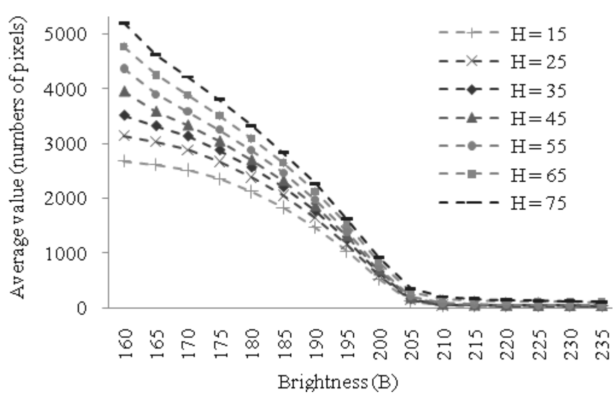

Figure 6. Number of false positve pixels according to brightness and hue

4. APPLICATION OF LASER DETECTION IN REMOTE CONTROL

Using webcam to capture the projection image of the screen on the wall, and having the video stream extracted into frames, the authors get the screen and its image in the frame. Because of the relative position between the webcam and the projector to the wall, the image of a computer screen on the wall in a webcam's viewpoint is not exactly rectangular but may be a trapezoid (keystone effect) or worse, a quadrilateral **Error! Reference source not found.**. So to get the information correctly, the application system requires a calibration implementation.

Based on the homography theory, the mapping between the projection image and the screen requires a fundamental (or transformation) matrix which helps compute the correspondent position of every position of a laser dot in the image of the projection screen. The local feature SURF algorithm helps to find sets of interest points of the screen and a frame. Then, K pairs of point from the 2 sets is chosen randomly to construct the transformation matrix. The matrix created is tested with other key points for reliability: a probability number is calculated based on the number of correctly matched interest points.The process is iterated until the probability number is accepted.

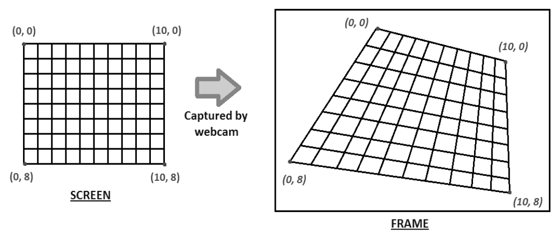

Figure 7. A screen's captured by a camera

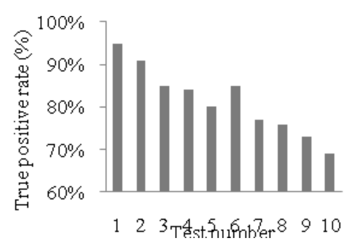

Figure 8. Accuracy in some real-time tests

With the calibration technique, the interest area on the image is focused, which helps to reduce the effects of other unwanted regions such as windows and so reduces the rate of false positive results. The real-time tests are set up based on the brightness and hue value feature of a laser dot. The environmental light can be divided into 3 categories dark, mid-range and light.

The projection screen can be classified as a static screen's image (test case 1, 2, 3, 4, 5) and dynamic, a screen with image changed during the test (test case 6, 7, 8, 9, 10). A special background, with mid-range and strong red channel is taken into tested (test case 4, 5 and 9, 10) since a laser dot is red, this kind of background may affect the accuracy of the system. For each kind of background, the environmental light is set to increase from dark (test case 1, 6) to mid-range (test case 2, 7) and to brightest (test case 3, 8).

Each test case is performed in 1 minute with a camera rate of 25 frames per second, yielding the total of 1500 frames per test case. With the brightness threshold of 205 and hue constraint of 75, the authors then count the number of frames that the system can correctly detect the laser dot over the total number of frames that is 1500. The result in **Error! Reference source not found.** provides the average accuracy rate of 82%. The accuracy rate is inverse proportional with the light of the environment: the darker the environment is, the higher the accuracy rate is, especially with the static background (test 1 and 2) where the accuracy rate is above 90%. In general case, for a certain environment, static background always helps produce higher accuracy than the dynamic background. This can be explained as when the background images are being changed the color regions on the background is changed and may interfere with the laser detection of the system. The worse case, the dynamic light red background can also bring the result above 60%.

5. CONCLUSIONS AND FUTURE WORKS

The authors propose a method to detect a laser dot for remote interactive systems using a laser pointer. The system detects and tracks a laser dot in frames from a video stream captured by a webcam and converts its movement into mouse cursor behaviors. Based on the observation that a laser spot is a very bright red spot, this detection method tries to specify it from other areas in a photograph using the brightness and color features.

The paper points out that the better way to describe the visual concept based features is to use the HSI color space instead of the normal RGB space and, more important, to detect laser dots the paper chooses brightness threshold to be 205 and the hue value range to be greater than or equal to 35 around the value of -4. However, the detection method is not suitable for general situation when the light is high and unsteady; instead, it is pretty good with average accuracy is about 82% for presentation purpose when the environment is usually dark and the camera is focused on a light-steady screen.

Although the authors try to use a calibration technique in the application section, this should be applied only when the visual angle from the webcam to the projection screen is wide enough and there should be more experiments about this so that information from a screen can be completely obtained by the camera.

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