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Locating Laser Sensors for Projector Touch Screens Using Triangulation Methods

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Abstract

An interactive whiteboard can either be a standalone computer or a large, functioning touchpad for computers to use. Recently, an interactive whiteboard system has been suggested to overcome the high cost, low resolution, and low scalability of large touchscreens of over 100 inches by using a laser optic module. When installing the whiteboard system with the laser optic module, it is important to position the laser optic module correctly because it determines the whole quality of the whiteboard operations. This paper derived triangulation expressions for locating laser optic modules. Compared to the previous works, the system that adapts our expressions can handle more flexible calibration points when measuring the positions of laser optic modules. This makes the installation and maintenance burdens of large-size whiteboards be easy.

Keywords: *Touchscreen, Projector, Laser Optic Module, Triangulation, Locating Problem.*

1. Introduction

An interactive whiteboard (IWB) device can either be a standalone computer with touchscreen or a large, functioning touchpad for computers to use. A device driver is usually installed on the attached computer so that the interactive whiteboard can act as a Human Input Device (HID), like a mouse. For the IWBs using projectors, the computer's video output is connected to a digital projector so that images may be projected on the interactive whiteboard surface. Users can then manipulate the elements on the board by using their fingers or pointing tools as a mouse, directly on the screen. They are used in various meeting situations, including classrooms for education, seminar rooms for corporative members, training rooms for coaching, studios for broadcasting, and others [1].

Various touchscreen technologies are used to implement IWBs and thus a technology determines the quality and property of the implemented IWB [2]. The technologies are classified into resistive, surface capacitive, projected capacitive, surface acoustic wave, acoustic pulse recognition, infrared grid, infrared acrylic projection, optical imaging, and dispersive signal technology. A touchscreen is a device with input and output functions usually topped on an electronic visual display of a computing system. A user can input or control the computing system via simple or multi-touch gestures by touching the touchscreen with pointing tools including one or more fingers [3].

Resistive touchscreen technology emerged as the first generation of touchscreens [4]. Two transparent electrically resistive layers are used for horizontal and vertical detections. When the user touches the screen, the two layers are connected at the touch point and work as voltage dividers, and the voltages are sensed to calculate the touch location. This technology suffers from poor durability and optical quality, and lack of multi-touch. Capacitive-based touch panels arrange electrodes as rows and columns. The electrodes are separated by an insulating material [5]. They have advantages of supporting multi-touch and maintaining the visibility and transparency of the visual display. It has disadvantage of high manufacturing cost when the size of touchscreen becomes large. The location of touch point is detected by acoustic waves in surface acoustic wave schemes [6]. The advantages of these technologies are lower cost, better optical performance, higher durability, and easier integration when comparing with capacitive-based technologies but it needs heavier force for touch and bigger bezel to install reflectors. The infrared grid technology uses an infrared grid pattern. Two adjacent bezel edges of a display are arranged with LEDs along the edges and the LEDs are facing photodetectors on the opposite edges [7]. When a touching object interrupts the grid of IR light beams, a controller calculates the touch coordinates. The technology is not adequate for interactive touchscreen applications due to low resolution, slow speed, and the size constraint of touch objects.

For camera-based optical technology, backlights of IR LEDs are provided in the corners of the touchscreen with a retroreflector around the periphery of the screen. Light is radiated from the edges of the screen across the top surface. When a finger touches the display, it interrupts the light and a shadow is seen by the cameras. Then the location of touch can be calculated with image processing and triangulation [8]. It has advantage of lower cost for larger touch screen but suffers from low resolution. Currently, there are many researches for human-machine interaction beyond 2-D touch interface [9] and [10].

Even though a touchscreen computer can be used for IWBs, touchscreen display technique suffers from high-cost and implementation difficulty for more than 100-inch displays [11]. Therefore, cheap and scalable touchscreen methods have been used for IWB implementation. Optical and ultrasonic methods are known to be the commercially available large-scale touchscreen technologies.

To overcome the high cost and implementation difficulty of large touch size, [12] introduced an IWB system that uses a laser optic module. The operation principle of the system is similar to the camera-based optic scheme. However, the system locates touches more accurately by using laser emitter instead of LED as a light source and simpler due to the absence of image processing. The system based on laser sensors requires triangulation calculations for touch point locating, positioning laser sensors, screen positioning, calibration, and distortion detection. In this paper, we generalized the triangulation methods developed in [12]. Especially, we focus on the geometric positioning of laser sensors for correct installation and checking the distortions that are generated by projectors due to the inherent mechanical or optical errors and sometimes due to installation errors.

This paper organized as follows. In Section 2, we present the operation principals of the IWB system that is using a laser optic modules. Section 3 derives generalized triangulation expressions for locating sensors and explains the application of the expressions for the installation and maintenance of whiteboard systems. The paper concludes with Section 4.

2. Whiteboard System Operation

Fig. 1 shows an ideal installation of the whiteboard system that uses laser optic modules. The main component is the laser optic module that contains two right and left laser sensors. Three reflective bars are installed left, right, and down sides of the projector screen. A projector that emits a computer display output forms a projector display on the projector screen. We can know all the geometrical values of the projector screen, the projector display, and the laser optic module in an ideal installation environment. However, every installations have errors due to incorrect installation of the screen, projector, and module and due to optical errors in the laser optic module and the projector.

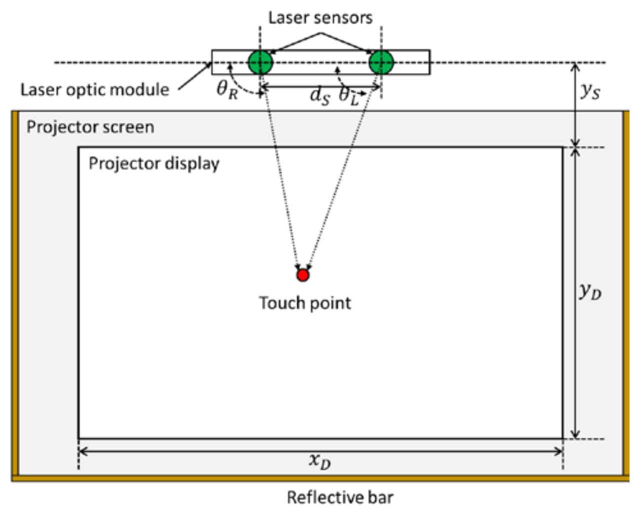

Fig. 1 The operational view of the laser sensor whiteboard.

Each laser sensor has a laser emitter, a light detector, and a 7200-rpm motor that rotates 45-degree prism counterclockwise. Fig. 2 shows the structure of the laser sensor and the real view of the optic module.

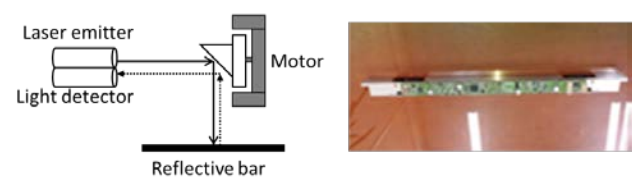

Fig. 2 The structure of the laser sensor and the real optic module.

The rotating prism reflects the light of the laser emitter so that the laser beam rotates 120 times every second. The beam scans the three reflective bars and non-reflection path of the upper side. The reflected light from the bars can be sensed by the light detector if there is no object that can block the emitted light on the projector screen. If the light detector senses the reflected light, the controller of the laser optic module generates high signal using the output of the light detector. The controller generates low signal when the emitted light goes through the non-reflection region or when an object on the projector screen absorbs and scatters the laser light.

The controller generates a continuous square wave if there is no object on the projector screen. The frequency of the wave is determined by the motor speed and it is 120 Hz in our system with a 7200-rpm motor. If an object is on the projector screen, a low-signal hole can appear during the high-signal part of the wave. We can measure the time from the start of the high signal to the middle of the hole by using an input capture hardware. Also, we can calculate the angle between the start point of the left reflective bar and the center of the object on the screen from the origin of the laser sensor by simple conversion of time to angle. If we use two right and left laser sensors with the known geometrical values, we can get the two angles, θ_R and θ_L, of Fig. 1 by adding the calculated angles between the straight line connecting the two laser sensors and the lines that connect the start point of the left reflective bar and the centers of the two laser sensors. Finally, we can calculate the position of the object on the projector screen by applying the triangulation methods [13]. Fig. 3 shows the signal examples generated from the laser optic module with no object, one object, and two objects on the projector screen.

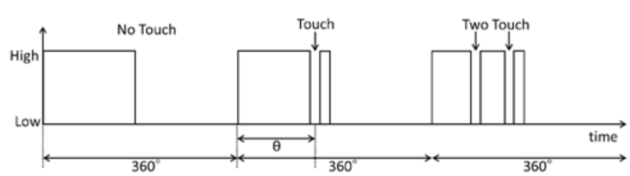

Fig. 3 Signals generated by laser optic module with or without objects.

Using the process mentioned above, we can implement an IWB system by touching the project display, which is the effective region of display output of the IWB system, with fingers or pointing tools which can block the laser light. When someone touches the projector display with multiple fingers, holes with the same number of fingers are generated and the controller of the IWB system can calculate the positions of all touches except for occlusive cases. There can be several occlusive cases due to the similar reasons of the camera-based optical technologies [8].

3. Generalized Triangulation Expressions and Applications

The IWB system is composed of a computer system, a beam projector and a projector screen installed on a wall, and the laser optic module. To install an IWB system, all the parts of the system have to be separately installed part by part. It is very difficult to install the parts at the predesigned correct positions and to make the system operate in a right manner as designed due to some installation errors or inherent errors of the parts. The laser optic module may not be installed in parallel to the x-axis of the projector screen or its center may not locate at the center of the projector screen. This installation error incurs an incorrect calculation of touch points.

The severer problem is the size and aspect ratio of the projector display shot by the actual projector. By the installation and optical errors of the projector, the IWB system may suffer from an image distortion. When an image is projected by the projector, the size of the pixels constituting the image may be changed by the installation status of the projector. The size and aspect ratio cannot be determined in advance, and after the installation, it is required to adjust the shape of the projected image in some limits. In order to determine each geometrical value of an IWB system on the 2-D plane, a metric unit and a reference point is required for specifying the location of each point. The correct invariant information of the system is the resolution of the projector display because it is set by the computer that originates the display. To tolerate all the errors incurred by IBW systems, we start from the resolution of the system as an invariant data. We devised a methodology to get a metric unit and we developed triangulation expressions for locating laser sensors or estimating the installation distortion using the devised metric unit.

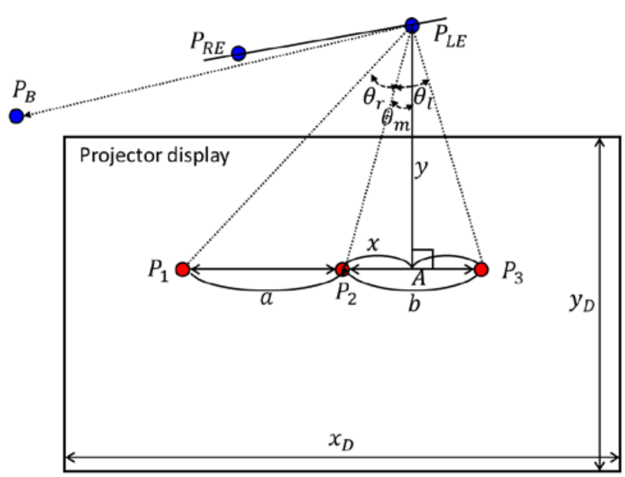

Fig. 4 Geometrical view for finding the position of the left laser sensor.

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We derive triangulation expressions to find the positions of two laser sensors using Fig. 4, where P_{RE} and P_{LE} are the positions of the right and left laser sensors. P_B is the position of the start of left reflexive bar. P_1, P_2, and P_3 are touched points and two angles θ_r and θ_l are measured by the left laser sensor. First, we derive an expression for the left laser sensor and the same method can be applied to the right laser sensor.

The display resolution is assumed to be known a priori and to be displayed without any distortion. If the display is the full HD resolution, then x_D is 1920 pixels and y_D is 1080 pixels if we use pixel as a metric unit. The three points (P_1, P_2, P_3) are displayed along with a line that is parallel to the horizontal line of the display. Let the distance of the line (P_1, P_2) be a and the distance of (P_2, P_3) be b with a pixel size units. The controller of the laser optic module measures the angle of the point if each point is touched. With the three measured angles, we calculate θ_r by subtracting the measured angle of P_1 from that of P_2. Similarly, θ_l is calculated with the measured angles of P_2 and P_3.

To derive trigonometric expressions for the location of the left laser sensor, a perpendicular is drawn from P_{LE} to the line (P_1, P_3) and let the intersection point be A. Let x be the length of the line (A, P_2) and let y be the length of the line (A, P_{LE}). We can calculate the location of the left laser sensor, P_{LE}, if we have expressions for x and y with θ_r, θ_l, a, and b, where θ_r and θ_l are measured values and a and b are known values. Using the tangent definition, we can get the following expressions Eq. (1), Eq. (2), and Eq. (3).

$$\tan\theta_m = x/y \tag{1}$$

$$\tan(\theta_r + \theta_m) = (a + x)/y \tag{2}$$

$$\tan(\theta_l - \theta_m) = (b - x)/y \tag{3}$$

By substituting x/y of Eq. (2) and Eq. (3) with Eq. (1), we can obtain Eq. (4).

$$\tan(\theta_r + \theta_m) - \tan\theta_m = a/y, \quad \tan(\theta_l - \theta_m) + \tan\theta_m = b/y \tag{4}$$

Using the tangent addition theorem, we can get Eq. (5) and Eq. (6) from Eq. (4).

$$\frac{\tan\theta_r + \tan\theta_m}{1 - \tan\theta_r \tan\theta_m} - \tan\theta_m = \frac{\tan\theta_r(1 + \tan^2\theta_m)}{1 - \tan\theta_r \tan\theta_m} = \frac{a}{y} \tag{5}$$

$$\frac{\tan\theta_l - \tan\theta_m}{1 + \tan\theta_l \tan\theta_m} + \tan\theta_m = \frac{\tan\theta_l(1 + \tan^2\theta_m)}{1 + \tan\theta_l \tan\theta_m} = \frac{b}{y} \tag{6}$$

Then, by deleting y from Eq. (5) and Eq. (6), $\tan\theta_m$ can be obtained with Eq. (7).

$$\tan\theta_m = \frac{a\tan\theta_l - b\tan\theta_r}{(a+b)\tan\theta_r \tan\theta_l} \tag{7}$$

Finally, the values of x and y can be calculated using Eq. (8) that are transformed from Eq. (4) and Eq. (1), where θ_m is the inverse of $\tan\theta_m$.

$$y = \frac{a}{\tan(\theta_r + \theta_m) - \tan\theta_m}, \quad x = y\tan\theta_m \tag{8}$$

We can find the position of the left laser sensor by measuring the angles between the three known horizontal points. The similar method can be applied to the right laser sensor. Using the measured position information of two laser sensors, we can verify the correctness of the optic module installation or can adjust the installation errors of the laser sensors.

The triangulation expression Eq. (8) is effective when the project display is installed correctly. There may be an x-y distortion when the sizes of x direction unit and y direction unit are different due to the incorrect installation of the projector or optic errors. To determine the x-y distortion ratio, we derived expressions using the measured angles with three vertically aligned touch points as shown in Fig. 5, where we assume that the projected screen is correct in horizontal direction. P_1, P_2, and P_3 are touched points and two angles θ_r and θ_l are measured by the right laser sensor.

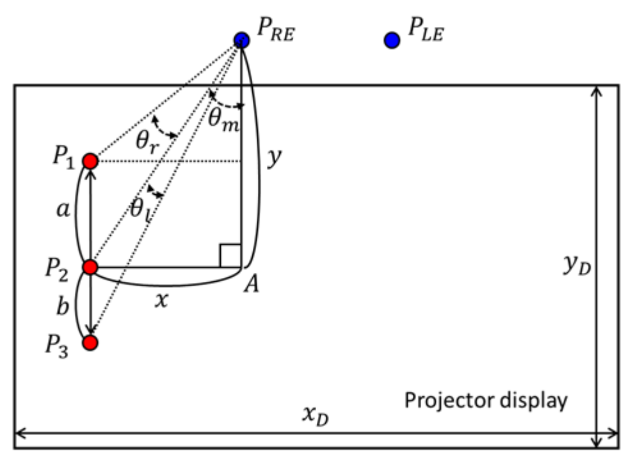

Fig. 5. Geometrical view for finding x-y distortion by measuring the length from P_1 to P_2.

We know the two values, a and b, and the two angles, θ_r and θ_l, are measured by the right laser sensor in Fig. 5. Then, we can get the following equations Eq. (9), Eq. (10), and Eq. (11).

$$\tan\theta_m = x/y \tag{9}$$

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$$\tan(\theta_r + \theta_m) = x / (y - a) \tag{10}$$

$$\tan(\theta_m - \theta_l) = x / (y + b) \tag{11}$$

By applying Eq. (9) to Eq. (10) and using the tangent addition theorem, we can obtain Eq. (12).

$$\frac{\tan\theta_r + \tan\theta_m}{1 - \tan\theta_r \tan\theta_m} = \frac{y \tan\theta_m}{(y - a)} \tag{12}$$

We can get Eq. (13) if we simplify Eq. (12) in terms of y.

$$y = \frac{a(\tan\theta_r + \tan\theta_m)}{\tan\theta_r (1 + \tan^2\theta_m)} \tag{13}$$

Similarly, we can get Eq. (14) from Eq. (11).

$$y = \frac{b(\tan\theta_m - \tan\theta_l)}{\tan\theta_l (1 + \tan^2\theta_m)} \tag{14}$$

By combining Eq. (13) and Eq. (14), $\tan\theta_m$ can be obtained with Eq. (15).

$$\tan\theta_m = \frac{(a + b)\tan\theta_r \tan\theta_l}{b \tan\theta_r - a \tan\theta_l} \tag{15}$$

Then, we can get x and y using Eq. (9) and Eq. (13). Finally, the measured a is obtained using Eq. (16) that is derived from Eq. (9) and Eq. (10).

$$a = \frac{x(\tan(\theta_r + \theta_m) - \tan\theta_m)}{\tan\theta_m \tan(\theta_r + \theta_m)} \tag{16}$$

We assumed that a is the pixel numbers of the line (P_1, P_2). The measured a of Eq. (16) will be the same to the assumed a if there is no x-y distortion in the project display. Therefore we can get an x-y distortion ratio by dividing the measured a of Eq. (16) with the number of pixels of a used to display the touch points.

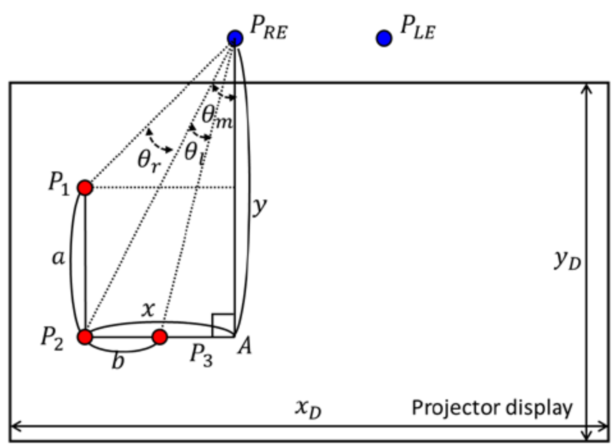

Fig. 6. Geometrical view for finding corner distortion by measuring the lengths x and y.

Distortion of the project display is prone to occur in the corner region of the display. We devised the method to calculate the degree of corner distortion compared to the center area. First, we find the locations of the laser sensors using three touch points at the center area as shown in Fig. 4. Then, we measure the locations of the sensors using three touch points of a corner area as shown in Fig. 6, where we assume that the projected screen has some distortion errors in the corner sides. P_1, P_2, and P_3 are touched points and two angles θ_r and θ_l are measured by the right laser sensor. With the values measured, we can estimate the distortion degree of a corner area.

We use three points, P_1, P_2, and P_3, which form a right angle in a corner area to find the location of the right laser sensor. The lengths a and b are known and two angles θ_r and θ_l are measured by the right laser sensor. Using the four values, we derives expressions for θ_m, x, and y. From the values of Fig. 6, we get the following equations Eq. (17), Eq. (18), and Eq. (19).

$$\tan\theta_m = x / y \tag{17}$$

$$\tan(\theta_r + \theta_m) = x / (y - a) \tag{18}$$

$$\tan(\theta_m - \theta_l) = (x - b) / y \tag{19}$$

The equations Eq. (17) and Eq. (18) are the same to Eq. (9) and Eq. (10). Therefore, by applying Eq. (17) to Eq. (18) and using the tangent addition theorem, we can obtain the same of Eq. (13). With the similar way to derive Eq. (6), we can derive Eq. (20) from Eq. (17) and Eq. (19).

$$y = \frac{b(1 + \tan\theta_m \tan\theta_l)}{\tan\theta_l (1 + \tan^2\theta_m)} \tag{20}$$

By combining Eq. (13) and Eq. (20), $\tan\theta_m$ can be obtained with Eq. (21).

$$\tan\theta_m = \frac{\tan\theta_r (a \tan\theta_l - b)}{\tan\theta_l (b \tan\theta_r - a)} \tag{21}$$

Then, x and y can be obtained as Eq. (22) from Eq. (17) and Eq. (19).

$$y = \frac{b}{\tan\theta_m - \tan(\theta_m - \theta_l)}, \quad x = y \tan\theta_m \tag{22}$$

By comparing the locations of the right laser sensor of the center and corner areas, we can estimate a distortioin error in the corner areas. Also, the measured a and b can be calculated with Eq. (18) and Eq. (19) and there may be a distortion error if the measured values are different with the presumed values as like the x-y distortion case.

In general, triangulation is the process of determining the location of a point by forming triangles to it from known points [13]. One of the main applications is navigation where the location of a moving objects is determined using only angular observations of objects with known coordinates [14]. We applied the triangulation method to

IWB systems that use two laser sensors to locate touch points. To overcome the installation difficulties of IWB systems, we derived several expressions that can be used to find the locations of the laser sensors and to measure the distortions of the installed project display.

4. Conclusions

The method using the laser optical module has the advantages that it has a simple structure of only two laser sensors regardless of the screen size and locating touch points is very accurate due to the characteristics of laser even for a large screen. The method can be a very adequate solution for large IWB systems assembled using projectors due to its low cost and scalability.

When using a projector for an IWB system with large screen size, it has difficulties to install the projector and related laser optic module precisely. The behavioral characteristics of the system may be altered from the initial settings due to the mechanical and optic stresses of the system. The system will be desirable to automate the tasks to install and maintain the IBW system.

This paper derived triangulation expressions for locating laser sensors and finding distortions on the project display. Compared to the previous works, the system that adapts our expressions can handle more flexible calibration points when measuring locations or distortions. This enables the installation burden of large-size IWB systems to be easy. The position of a laser sensor can be calculated only by touching the three displayed points on the projector display, and the distortions of the display can be checked and corrected with the same method.

Acknowledgments

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