High-resolution and compact virtual mouse using lens arrays to capture finger images on light sensors

Zong Qin (SID Member)
Yu-Cheng Chang
Yu-Jie Su
Yi-Pai Huang (SID Senior Member)
Han-Ping D. Shieh (SID Life Fellow Member)

Abstract — To realize a finger positioning device, as called “virtual mouse,” to replace a touchpad, touchscreen, or even real mouse, current positioning technologies cannot achieve a sufficient resolution, a compact volume, and a simple detection algorithm simultaneously. For this problem, using a light-emitting diode source, two lens arrays, and two light sensors, we design and implement a virtual mouse prototype. The optical architecture is carefully determined for a compact volume, a sufficient resolution, and a high detection accuracy. Corresponding to a compact system volume of 3.1 mm (thickness) × 4.5 mm (length) × 2, a theoretical resolution higher than 25 pixels per inch (ppi) can be obtained over a working area of 10 cm × 10 cm. Experiments are also implemented, in which a mean detection error of 0.24 cm that corresponds to approximately two distinguishable points, and a minimal resolution of 26 ppi over the whole working area are verified. If the system thickness is relaxed to 25 mm, a resolution higher than 200 ppi can be achieved. The proposed virtual mouse, which is simple enough and potential to be extended for three-dimensional position detection, can be integrated with a flat panel display to achieve a compact display application that can interact with users.

Keywords — position detection, virtual mouse, first-order optics, lens array.
DOI # 10.1002/jsid.613

1 Introduction

The concept of virtual mouse refers to a way users move their finger(s) in a free space instead of using a real mouse or on-device touch for an electronic device, such as notebook and tablet, as shown in Fig. 1.1-4 The positional information of human finger(s) is detected by the virtual mouse and provided to the device. Therefore, with the aid of a virtual mouse, users can comfortably free their hands from being restricted in the region of touchpad or touchscreen, or get rid of a real mouse while traveling with notebooks. If the virtual mouse is compact enough, it can also be integrated with a flat panel display to realize a compact display application interacting with users. In light of this, a practical virtual mouse generally provides several key features, including (1) a working area beside an electronic device with a working distance (Fig. 1), where users can comfortably move their finger(s); (2) a resolution comparable with that of current products, as 25 pixels per inch (ppi) for touchpad or touchscreen, and 200ppi for opto-mechanical mouse5; (3) an acceptable detection accuracy, as a detection error of no more than one or two distinguishable points5; (4) a compact volume in consideration of the demand of being integrated with a flat panel display; and (5) a simple detection algorithm for fast response and low cost.

Current technologies that are potential to realize such a virtual mouse mainly include dual-camera positioning, structured light, time of flight, and integral imaging.6-14 These technologies have achieved great success in different application fields; however, they have respective shortcomings in consideration of the particular requirements of a virtual mouse. For instance, the structured light technology introduced by Andrews and Litchinitser7 and integral imaging technology introduced by Traver et al.8 call for powerful computing capacity; the time of flight technology introduced by Breuer et al.9 has a relatively high cost; and the dual-camera positioning technology introduced by Morrison10 leads to a considerable volume. Therefore, a new technology simultaneously having a sufficient resolution, a compact volume, and a simple detection algorithm is still demanded to develop a practical virtual mouse.

In this paper, a virtual mouse prototype is designed and implemented. A light-emitting diode (LED) source illuminates a finger, and then two lens arrays designed in-house capture several images of a finger on two linear light sensors. According to positions of the several finger images and the system configuration, the finger position can be obtained by intersecting chief rays of the several imaging paths. As a result of the optical design, on one hand, benefiting from the simple single-element imaging, the system volume is as compact as 3.1 mm (thickness) × 4.5 mm (length) × 2, which is much smaller than that of a typical camera-based positioning device. On the other hand, an acceptable detection accuracy is
guaranteed by jointly utilizing several imaging paths. The dense pixels on the light sensors also guarantee that the finger movement can be sensitively reflected by the image movement; that is, a sufficient resolution. Performances of the proposed virtual mouse are also verified by experiments, including a mean detection error corresponding to only two distinguishable points, and a minimal resolution of 26 ppi over the working area, which is comparable with that of current touchpads or touchscreens. If the system thickness is relaxed to 25 mm, the resolution can be higher than 200 ppi. In addition, the proposed virtual mouse can be easily extended for three-dimensional (3D) position detection by using a two-dimensional light sensor.

2 Optical architecture

In our study, to detect the finger position, two lens arrays respectively covering on two light sensors are adopted, as shown in Fig. 2. An LED source is placed in the middle of the two lens arrays. A finger moving in the working area reflects light; then the convex lenses converge light and generate several images of the finger on the light sensors. Consequently, as long as we obtain the signals of the two light sensors and recognize separated finger images, the finger position can be known, as on the chief rays of the several imaging paths. As more than one images are captured, the intersection points of the several imaging paths can determine

Qin et al. / High-resolution and compact virtual mouse
the finger position. This optical architecture can realize finger position detection theoretically; however, to achieve a sufficient resolution and accuracy for a practical virtual mouse, parameters including lens amount, lens pitch, baseline length, sensor length, sensor-lens gap, and focal length need to be carefully determined. In case that pixel size of the light sensors is 2 μm, following discussions will introduce how to determine these parameters for a working area with a size of 10 cm × 10 cm and a working distance of 12 cm.

2.1 Sufficient resolution

The resolution in ppi is defined as the number of pixels the light sensors “perceive” when the finger moves for 1 in. To work out the resolution theoretically, a pinhole model is used to approximate our system, as shown in Fig. 3. Additionally, as shown in Fig. 2, six lenses in two lens arrays are adopted in our system, and the middle lens in each lens array are painted black (the way we set lens arrays will be explained in Section 2.2). In this way, in the pinhole model in Fig. 3, there are four imaging paths. Obviously, the object movement perpendicular to the lens arrays is reflected by the image point shift less sensitively than the other movement directions are; hence, the resolution along the direction perpendicular to the lens arrays, as called vertical resolution $RV$, determines the system resolution. Moreover, the image point of the outermost lens in the lens arrays will shift for the most when the object point moves perpendicular to the lens arrays. Therefore, the outermost lens is considered to calculate $RV$. On the basis of the geometry in Fig. 3, when an object point is located at $(X,Y)$, the image position $M$, relative to the sensor’s center, can be calculated by Eq. (1), which is based on the similar triangle principle. When the object point is moved for 1 in. against the lens array to be located at $(X,Y + 25.4 \text{ mm})$, the image position can be calculated similarly. By calculating the difference value between the image positions before and after moving the object point, and converting to pixel number, $RV$ can be obtained by Eq. (2). Here, because of the working area of 10 cm × 10 cm, as well as the coordinate system in Fig. 2, $X$ and $Y$ vary between −5 and 5 cm and 0 and 10 cm, respectively. Here, it should be noticed that the direction perpendicular to the lens arrays has the lowest resolution. If the lens arrays are placed obliquely relative to the electronic device, for example, notebook or tablet, a new direction that is also perpendicular to the lens arrays will have the lowest resolution, whereas it is not perpendicular to the device. Because the finger may move along an arbitrary direction in the working area, it makes little sense to use oblique lens arrays only to increase the resolution along the direction perpendicular to the device. In addition, an oblique configuration increases the actual volume of the virtual mouse system for the electronic device. Therefore, the side-by-side configuration used in this study is optimum.

$$Y = \frac{BL/2 + d + X}{M + X}$$

$$RV \text{ (in ppi)} = 25.4 \times \left[ \frac{G(BL/2 + d + X)}{\mu Y^2} + \frac{1}{Y} \right]$$

where $BL$ is baseline length, $d$ is lens pitch, $G$ is sensor-lens gap, and $\mu$ is pixel size.

From Eq. (2), the smallest vertical resolution $RV$ occurs at $X = 0 \text{ cm}$ and $Y = 10 \text{ cm}$; that is, the middle point of the farther edge of the working area. Now, we want the virtual mouse to replace a conventional touchpad or touchscreen with a resolution of 25 ppi; moreover, the sensor-lens gap $G$ should be small in consideration of a compact system volume. In light of these, when the pixel size $\mu$ is 2 μm, a reasonable solution for $RV = 25 \text{ ppi}$ at $X = 0 \text{ cm}$ and $Y = 10 \text{ cm}$ is $BL = 60 \text{ mm}$, $G = 3 \text{ mm}$, and $d = 1 \text{ mm}$. On the basis of these parameters, we plot the variation of $RV$ corresponding to $X = 0, X = 2.5 \text{ cm}$, and $X = 5 \text{ cm}$, respectively, while $Y$ varies from 0 to 10 cm, as shown in Fig. 4(a). The resolution is higher than 25 ppi in the whole working area. If the sensor-lens gap $G$ is relaxed to 25 mm, the resolution over the whole working area can be higher than 200 ppi, as shown in Fig. 4(b), which is comparable with that of a real mouse. Noticeably, the resolution calculated on the basis of the pinhole model may be a little different from the actual value; hence, the resolution should be further verified by experiments, as discussed in Section 4.

2.2 Separated images

After determining sensor-lens gap $G = 3 \text{ mm}$, baseline length $BL = 60 \text{ mm}$, and lens pitch $d = 1 \text{ mm}$, we need to further determine lens amount, focal length, and sensor length to guarantee that the images are separated when the finger is located at any position in the working area; that is, any field of view. Only in this way, we can recognize several finger images to calculate the finger position.

First, because of the considerable aberration produced by single-element imaging, the finger images will be distorted. Moreover, an aspheric lens or multi-element lens system, which can effectively suppress aberration, will not be utilized.
in our system because they lead to a significantly higher cost and larger thickness. Therefore, more than two imaging paths should be utilized and only the chief ray in each imaging path will be considered to suppress the detection error caused by the aberration. In light of this, six lenses in two lens arrays with a baseline length $BL = 60$ mm, which was determined before, are adopted, and the middle lens in each lens array is painted black, as shown in Fig. 2, to further guarantee that images are separated.

Next, by considering that the produced images are blurred due to the depth of focus while the finger moves in the working area, we should find out a focal length that obtains images as small as possible over the whole working area to prevent image superposition. The lens pitch (lens aperture) has been determined as $d = 1$ mm, then the ratio of the blurred image’s diameter to the lens aperture is adopted to quantitatively describe the defocusing, as the defocusing coefficient $D$ shown in Eq. (3) and Fig. 5.\textsuperscript{15} To determine the optimum focal length, $D$ varying in the working area ($0 \text{ cm} < Y < 10 \text{ cm}$) corresponding to different focal lengths is shown in Fig. 6, from which the focal length of 2.9 mm is selected as the optimum one because it can achieve smaller values of $D$ in the working area than other focal lengths can.

$$D = \frac{A}{B} = |1 - G/f + G/Y|$$  \hspace{1cm} (3)

After determining the lens amount and focal length, we need to quantitatively verify that finger images are separated on the light sensors and then determine the sensor length to make the images not exceed the range of the sensors. For the verification, fundamental Gaussian Optics can be adopted to calculate sizes and positions of the images; however, a little error will be introduced. Therefore, we directly adopt raytracing simulations in LightTools 8.5 to acquire accurate results.\textsuperscript{16} In the simulation, a cylindrical source with a length of 10 cm and a radius of 0.5 cm is set up to simulate a human finger. By placing the central point of the cylindrical source at six representative positions, as shown in Fig. 7(a), irradiance distributions on the sensor plane are simulated. Figure 7(b) shows the simulation results, where four clearly separated images can be always produced on the two sensors with the smallest space of 0.54 mm. As can be seen from Fig. 7(b), when the finger is located on the middle line of the working area (positions ①, ②, and ③), the signals generated on the two sensors are symmetric to the $y$-axis. On the other hand, when the finger is located at the edge line of the working area (positions ④, ⑤, and ⑥), the signal on the sensor farther to the finger deviates from the sensor center more. In the simulations, the sensor length is adjusted to 4.5 mm to just cover the images corresponding to the six representative positions, which can be also seen in Fig. 7(b).

For the parameter determination discussed previously, the working area ($10 \text{ cm} \times 10 \text{ cm}$) and working distance ($12 \text{ cm}$) are given in advance. In fact, they are not given without cause. On the one hand, if the working distance is smaller, more oblique light incident on the lens arrays will call for a longer sensor. On the other hand, if the working distance is larger, the resolution will be insufficient, because the resolution is fast decreased with an increasing finger-to-lens distance (Fig. 4). In addition, a $10 \text{ cm} \times 10 \text{ cm}$ square is very close to the conventional moving range of a real mouse. Therefore, it is in consideration of the resolution, sensor length, and operator comfort that we determine the working area and working distance.

\textbf{FIGURE 4} — Vertical resolution varying with $Y$ from 0 to 10 cm: (a) sensor-lens gap $G = 3$ mm; (b) sensor-lens gap $G = 25$ mm.

\textbf{FIGURE 5} — Calculation schematic of the defocusing coefficient $D$. 

Qin et al. / High-resolution and compact virtual mouse
In conclusion, six lenses with a pitch of 1 mm and a focal length of 2.9 mm, including two painted black, are arranged in two lens arrays with a baseline length of 60 mm. The gap between the lens arrays and the sensors, whose length is 4.5 mm and pixel size is 2 $\mu$m, is 3 mm. If the lens arrays are made up of acrylic material, the overall thickness comprising the gap and lens arrays is 3.10 mm.

3 Detection algorithm

After four finger images are captured on the light sensors, a detection algorithm is needed to determine the finger position. In addition to a sufficient detection accuracy, computations of the algorithm should be as simple as possible in consideration of the requirement of fast response and low cost. Here, a detection algorithm with low computation amount is proposed, which comprises two simple procedures.

3.1 Pre-processing

First, noises in captured raw signals should be reduced with a denoise filter, such as a mean filter. Next, a threshold should be used to eliminate low-luminosity stray light that may be caused by background. Finally, the processed signal should be binarized, and clear images with definite edges will be obtained on each sensor. Theoretically, according to our simulation in the last section, four complete images, whose...
two edges are both located on a sensor, should be captured. Nevertheless, in reality, a finger longer than 10 cm or exceeding the working area a little may cause one of the images to be incomplete, especially when the finger is located in the close corners of the working area. This does not matter because we use multiple lenses to capture images; that is, complete images will be considered for the subsequent processing while incomplete ones will be discarded. Moreover, between two images on a sensor (despite complete or incomplete ones), a dark pattern always exists, which will also be considered in the subsequent processing.

3.2 Determining of finger position

After pre-processing, at least two and at most four images along with two dark patterns will have been obtained on two sensors. Next, the center of each image should be determined to be the position of an image generated by the corresponding lens, including dark patterns corresponding to the painted lenses. In our setup, sensors are directly covered on the bottom of lens arrays; that is, no air gap exists; hence, a thick lens immersed in air on both sides is considered. Its node points coincide with principal points, as $N_1$ and $N_2$ shown in Fig. 8. On the basis of the graphical method of thick lens imaging, a chief ray can be drawn from an image point to the object space. Several intersection points can be obtained between pair-wise chief rays. Finally, the average position of these intersection points will be determined to be the finger position. The whole detection algorithm is illustrated in Fig. 8. By considering that the graphical method of thick lens imaging based on node points is just the first-order property of an imaging system, the accuracy of this method should be experimentally verified in the next section.

4 Experimental results

Figure 9 shows our experimental architecture. The lens arrays are fabricated by Coretronic Corp., Taiwan, and a 10-cm-long fake finger assembled on a 2D track is used to simulate a moving human finger. In addition to that, surface of the fake finger is diffusely reflective, and denoise and binarization will
be implemented for the captured images. Therefore, brightness of the images can be always uniform after the pre-processing; that is, placement of the LED source does not affect the captured signals. For the moment, we are not able to obtain the expected linear light sensors with a pixel size of 2 \( \mu \text{m} \). Instead, two 2D CMOS sensors with a pixel size of 4 \( \mu \text{m} \) and a dimension of 4.5 mm × 3 mm from commercial webcams are used. In this way, the resolution of this prototype will be half of the design value. Moreover, this verifying experiment is implemented in a darkroom, and reflectance of the fake finger is much higher than that of other apparatuses; therefore, the interference signal is ignorable. Considering that interference signal may be a trouble in practical applications, some anti-interference measures, such as using an infrared source, can be further used to make this prototype more practical after the optical system is verified.

4.1 Detection accuracy

The six representative finger positions in Fig. 7 are experimentally investigated. To locate the center of the fake finger at the six finger positions, the position of 5 cm (finger length: 10 cm) on the finger surface facing the lens arrays is made to coincide with the six prescribed positions by moving the track. Next, six by two raw signals are captured, as shown in Fig. 10(a). In the pre-processing, a mean filter with a filter size of five is used to reduce the noise, and then a threshold

---

**FIGURE 10** — Corresponding to six finger positions: (a) raw signals; (b) binary images after pre-processing; and (c) extracted 1D patterns, where the red marks denote central points of the complete light patterns and dark patterns.
of 10% full-on grayscale is used to cut off stray light, resulting in clear binary images, as shown in Fig. 10(b). Considering that the 2D sensors used in the experiments are just a replacement of the linear sensors in the design, the row of pixels that vertically face the lens arrays are extracted, and 1D patterns are obtained, as shown in Fig. 10(c). Note that it seems that an image identification method, such as fingertip recognition, can be implemented from the 2D signals in Fig. 10(a).

Nevertheless, to make our virtual mouse have a simple architecture and detection algorithm, as mentioned before, we propose to only use linear light sensors. The 2D sensor used in the experiments is just a replacement of 1D sensor, as shown in Fig. 10(c), where only the 1D signals are utilized for detection. From the 1D signals in Fig. 10(c), two complete images are obtained on each sensor in most cases. However, when the finger is located at positions ① and ④, one of the two images may exceed the sensor. As mentioned before, allowing some of the images to exceed the sensor can help to avoid an excessively long sensor for a compact system volume. Finally, the finger position determination can be subsequently implemented as more than two images have been obtained.

According to the detection algorithm introduced in Section 3, the central points of the complete images and dark patterns are found and marked red in Fig. 10(c). Chief rays are drawn with the method illustrated in Fig. 8; then finger positions are achieved via average positions of the intersection points produced by pair-wise rays. Corresponding to the six cases, the finger positions are listed as follows: ①(\(x = -0.22\) cm, \(y = 0.06\) cm), ②(\(x = -0.25\) cm, \(y = 5.07\) cm), ③(\(x = -0.20\) cm, \(y = 10.16\) cm), ④(\(x = 5.18\) cm, \(y = -0.09\) cm), ⑤(\(x = 5.20\) cm, \(y = 5.11\) cm), and ⑥(\(x = 5.31\) cm, \(y = 9.92\) cm). Figure 11 shows detected and actual finger positions comparatively. Because it is the relative but not absolute positions that a mouse utilizes, the average error of the detected positions is calculated in x- and y-axes directions, as 0.00 and 0.04 cm, respectively. By offsetting the detected positions with the opposite number of this average error, compensated finger positions are as follows: ①(\(x = -0.22\) cm, \(y = 0.02\) cm), ②(\(x = -0.25\) cm, \(y = 5.03\) cm), ③(\(x = -0.20\) cm, \(y = 10.12\) cm), ④(\(x = 5.18\) cm, \(y = -0.13\) cm), ⑤(\(x = 5.20\) cm, \(y = 5.07\) cm), and ⑥(\(x = 5.31\) cm, \(y = 9.88\) cm). Thus, the mean detection error is 0.24 cm. For a resolution of 25 ppi, each distinguishable point corresponds to 0.10 cm; hence, the mean detection error of our virtual mouse corresponds to approximately two distinguishable points. Although such a performance of detection error needs to be furthermore suppressed, it can be accepted by most touchpad, touchscreen, or even mouse applications.

4.2 Resolution

To verify the resolution performance, which is another key performance of a virtual mouse, the fake finger is moved along x-axis (lateral) and y-axis (vertical) directions for 1 cm, respectively. For instance, corresponding to case ①, the finger is first moved from (\(x = -0.5\) cm, \(y = 0\) cm) to (\(x = 0.5\) cm, \(y = 0\) cm), and then from (\(x = 0\) cm, \(y = -0.5\) cm) to (\(x = 0\) cm, \(y = 0.5\) cm). Before and after every moving operation, the positions of central points of all the complete light patterns and dark patterns are recorded. The central point with the largest variation during the finger moving is selected to calculate the resolution. The pixel number corresponding to the largest central point variation divided by 1 cm (0.39 in.) is just the value of resolution. Table 1 shows the experimental results, where the minimal resolution over the whole working area is 13 ppi. It must be pointed that a pixel size of 4 μm is actually used in the experiments as we are not able to obtain a higher-class sensor. If sensors with a pixel size of 2 μm are used, the minimal resolution will be naturally doubled to 26 ppi, which matches well with the theoretical resolution calculated before (25 ppi), and comparable with that of a conventional touchpad or touchscreen.

5 Discussions

The proposed virtual mouse prototype with a dimension of 3.1 mm (thickness) × 4.5 mm (length) × 2 has been verified

<table>
<thead>
<tr>
<th>Finger position</th>
<th>Pixel number</th>
<th>Lateral Resolution</th>
<th>Vertical Pixel number</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>①</td>
<td>50</td>
<td>127ppi</td>
<td>10</td>
<td>26ppi</td>
</tr>
<tr>
<td>②</td>
<td>30</td>
<td>76ppi</td>
<td>7</td>
<td>18ppi</td>
</tr>
<tr>
<td>③</td>
<td>15</td>
<td>38ppi</td>
<td>5*</td>
<td>13ppi</td>
</tr>
<tr>
<td>④</td>
<td>52</td>
<td>133ppi</td>
<td>14</td>
<td>36ppi</td>
</tr>
<tr>
<td>⑤</td>
<td>31</td>
<td>79ppi</td>
<td>10</td>
<td>26ppi</td>
</tr>
<tr>
<td>⑥</td>
<td>15</td>
<td>38ppi</td>
<td>7</td>
<td>18ppi</td>
</tr>
</tbody>
</table>

*Minimal value.
to have a minimal resolution of 26 ppi if a pixel size of 2 μm is used; hence, it is potential to replace a current touchpad or touchscreen. According to the resolution calculation, if the system thickness is relaxed to 25 mm and a pixel size of 2 μm is still used, a resolution higher than 200 ppi can make our virtual mouse potential to replace a real mouse. If the system is required to be more compact, a sensor with a smaller pixel size, such as 1 μm, can be adopted so that the sensor-lens gap can be narrower to trade-off between resolution and system volume. Furthermore, if part of the palm is also captured in the case of a real finger, the object including the finger and part of the palm can be considered as a whole to be used, because it is the relative position that a mouse uses rather than the absolute position. Nevertheless, when the relative geometrical relationship between the finger and the palm changes, a certain movement of the object including the finger and the palm will be detected, even if the fingertip is fixed. This issue should be considered in our future work.

Additionally, no technical barrier exists while extending this 2D virtual mouse to a 3D one. As long as a 2D light sensor is used instead of a linear sensor, a finger moving in the z-axis direction can be reflected by an image moving in the z-axis direction on the 2D sensor. Because the situation in the x- and z-axes directions is identical, the resolution in the z-axis direction will be equal to that in the x-axis direction. The sensor length in the z-axis direction should be determined according to the requirement of the working area’s depth. In fact, the patterns in Fig. 10(a) and (b) will move vertically when the finger is moved along the z-axis direction because we used a 2D sensor in the experiments. In our future work, the currently used experimental architecture will be extended to implement a 3D virtual mouse. Accuracy and resolution will be investigated for 3D situation. Moreover, gesture control will be discussed as 3D positional information can be captured.18–20

6 Conclusion

In this paper, an optical architecture comprising an LED source, two lens arrays, and two light sensors was proposed to realize a virtual mouse. For a given working area with a size of 10 cm × 10 cm and a working distance of 12 cm, parameters including lens amount, lens pitch, baseline length, sensor length, sensor-lens gap, and focal length were carefully determined to guarantee a high-resolution, a sufficient detection accuracy, and a compact system volume. As a result of the design, the system volume was 3.1 mm (thickness) × 4.5 mm (length) × 2, which is much smaller than that of a typical camera-based device. Moreover, a simple detection algorithm was proposed. Experiments were implemented to verify our design. The mean detection error was verified to be 0.24 cm, which corresponds to approximately two distinguishable points under a resolution of 25 ppi. For practical mouse applications, such a detection error is acceptable. Additionally, using light sensors with a pixel size of 4 μm, the measured minimal resolution over the working area was 13 ppi. If the expected pixel size of 2 μm is used, the minimal resolution will be naturally doubled to 26 ppi, which is comparable with that of a conventional touchpad or touchscreen. If the system thickness is relaxed to 25 mm and a pixel size of 2 μm is still used, the resolution can be further enhanced to 200 ppi to compete with a real mouse.

For a virtual mouse, this study achieved a sufficient detection accuracy, a resolution comparable with that of current products, a compact volume, and a simple detection algorithm simultaneously, while current technologies, which are although with excellent performances, have a certain shortcoming or another. Therefore, the proposed prototype is practical to replace a touchpad, touchscreen, or even real mouse for more convenient operations. Additionally, if the prototype is extended to a 3D positioning device by easily using a 2D sensor, and integrated with a flat panel display in consideration of its compactness, a display application having a 3D interaction function can be achieved with a compact volume and low cost.

Acknowledgments

This work was supported by Coretronic Corp., Taiwan and Ministry of Science and Technology (MOST) of R.O.C. projects under grant numbers 102-2221-E-009-167-MY3 and 102-2221-E-009-168-MY3.

References


Zong Qin received his B.S. degree in optical engineering and PhD degree in mechanical engineering from Huazhong University of Science and Technology, Wuhan, China, in 2008 and 2013, respectively. He is now working at National Chiao Tung University, Taiwan (ROC), as an assistant research fellow. His research interests are mainly focused on display optics, applied vision, and opto-mechanical system design.

Yu-Cheng Chang received the B.S. degree from the Department of Electrophysics, National Chiao Tung University, Hsinchu, Taiwan, in 2007 and is currently working toward the PhD degree at the Department of Photonics, Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu, Taiwan. He was an intern with TP Vision in the Netherlands in 2012. His current research includes backlight system design, 3D displays, optical system design, and head tracking systems.

Yu-Jie Su received the B.S. degree from the College of Electrical and Computer Engineering, National Chiao Tung University, Hsinchu, Taiwan, in 2013 and is currently working toward the M.E. degree at the Department of Photonics, Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu, Taiwan.

Yi-Pai Huang received his B.S. degree from National Cheng Kung University in 1999 and earned a PhD in Electro-Optical Engineering at National Chiao Tung University in Hsinchu, Taiwan. In 2004, he was a project leader at the technology center of AU Optronics (AUO) and was a visiting associate professor at Cornell University in 2011. He is currently a full-time professor in the Department of Photonics and Display Institute at National Chiao Tung University. His expertise includes 3D display and interactive technologies, display optics and color science, and micro-optics.

Han-Ping D. Shieh received his B.S. degree from National Taiwan University in 1975 and his PhD in Electrical and Computer Engineering from Carnegie Mellon University, Pittsburgh, PA, USA, in 1987. He joined National Chiao Tung University (NCTU) in Hsinchu, Taiwan, as a Professor at the Institute of Electro-Optical Engineering and Microelectronics and Information Research Center (MIERC) in 1992 after serving as a Research Staff Member at IBM Tj Watson Research Center, Yorktown Heights, NY, USA, since 1988. He is now the Vice Chancellor, University System of Taiwan and AU Optronics Chair Professor. He is a fellow of IEEE, OSA, and SID (Society for Information Display). He has also held an appointment as a Chang Jiang Scholar at Shanghai Jiao Tong University since 2010.