Mobile User Interface Using a Robust Fingertip Detection Algorithm for Complex Lighting and Background Conditions

Byung-Hun Oh*, Jun-Ho An and Kwang-Seok Hong

School of Information and Communication Engineering, Sungkyunkwan University, Republic of Korea

Abstract. This paper proposes the robust fingertip detection method using the Adaboost algorithm under dynamic lighting conditions and against complicated backgrounds for a finger-gesture-based mobile-user interface system. The proposed system is composed of two modules. First, the fingertip detection method is composed of two pre-processing phases using color and gradient information, AND an operation phase, and fingertip region detection using the Adaboost algorithm as sequential steps. Second, a user interacts with a mobile application by using finger gestures with the point change that are detected by the Adaboost algorithm. As a result, the proposed fingertip detection method is very effective under varying lighting conditions and against complex backgrounds, and mobile applications can be controlled by the proposed finger gesture-based mobile user interface system.

Keywords: Fingertip detection, Adaboost algorithm, Mobile UIs

1. Introduction

Because of recent research on new types of input interface systems, the latest mobile devices can support a variety of UIs ranging from keypads to multi-touch screens and sensor. For example, accelerometers and gyro-sensors could be added to mobile devices to support new UI types. However, as the number of UI sensors increases, the sensors will become difficult to integrate into existing small form-factor mobile devices at the hardware level [1, 2]. Vision-based mobile UIs, however, can serve as an important way to use camera-equipped mobile devices because, with their use, no new hardware is necessary.

Vision-based human-computer interaction is a popular research topic, and computer vision has been increasingly used to control such interface systems. Interactions with mobile devices such as smart phones and personal digital assistants have also become a potential application area, especially for the wireless industry. A gesture-based UI can directly use hands and fingers as a natural means to communicate with a device [3]. Further, users can interact more intuitively with mobile devices than with traditional UIs. Therefore, we propose the robust fingertip detection method using an Adaboost [4, 5] algorithm under dynamic lighting conditions and against complicated backgrounds for a finger-gesture-based mobile user interface system.

2. Proposed Method

2.1. System architecture

Figure 1 shows the implementation details of the proposed architecture that can accurately detect a fingertip from a single image captured by mobile phone camera. For robust fingertip region detection under conditions with complex backgrounds and illumination variation, the detection module is composed of two pre-processing procedures with input image and fingertip region estimation using the Adaboost algorithm as sequential steps. The two pre-processing procedures used are pre-processing based on gradient information and pre-processing based on color information. An AND image between the morphological gradient

* Corresponding author. Tel.: 82-31-290-7196; fax: 82-290-7998
E-mail address: sincelife@skku.edu
combination image and the color-base pre-processed image is finally used as an input of the Adaboosts algorithm to detect fingertip region. The estimated coordinates and area of the fingertip is then further refined and fed into the finger gesture recognition module, which determines the commands of mobile applications.

![Fig. 1: Proposed system architecture](image1)

2.2. Pre-processing

Figure 2 shows the results of the pre-processing procedure of the fingertip detection method. For the skin color segmentation, each pixel is classified as being either skin or non-skin and is converted into a new binary image with the threshold value analysis defined as follows:

$$\text{SkinColor}(x, y) = \begin{cases} 1 & \text{if} \quad (77 \leq C_r \leq 127) \land (133 \leq C_h \leq 173) \\ 0 & \text{Otherwise} \end{cases} \quad (1)$$

To reduce the effects of small background objects in the binary image, two basic morphological operations are performed; non-skin color objects that are larger than the 3 by 3 structuring element still exit. To remove large objects except for the finger region, we labelled each blob.

An obvious gradient value cannot be acquired by using only a gray image because of the equalizing effects of red, green, blue(RGB) to gray conversion. Thus, we devise the maximum morphological gradient values in the split R, G, and B planes and combine them into a single image. This allows for clearer gradient values than those of a gray image. The Maximum Morphological Gradient Combination(MMGC) image is defined in the following equation:

$$\text{MMGC} = \sum_{i} \sum_{j} \text{max}(MG_r(i, j), MG_g(i, j), MG_b(i, j)) \quad (2)$$

![Fig. 2: Results of pre-processing procedure of the finger detection](image2)
Finally, we can obtain an AND image between MM GC and the result image of the skin color segmentation and blob detection. The fingertip detection from the AND image, which includes the clear gradient information and the non-skin color subtraction, has higher performance than that from the original image.

2.3. Fingertip detection based on Adaboost algorithm

For our fingertip detection system, we collected the half-circle area images of the fingertip from the results of pre-processing as positive samples. The samples were collected under various illumination conditions. The number of the collected positive samples is 2,240, and 4,500 images from the results of pre-processing are collected as the negative samples for the training process. The fingertip cascade classifier is a 13-stage cascade that is 20 x 10 in size.

2.4. Mobile interface

In the proposed system, finger gestures can be performed for the operations of click, up, down, left and right. They can play the same role as a directional keypad and mouse. All of the directional commands except click are defined by chessboard distance. The moved distance, direction and the instant speed of the finger point between two frames determines the directional commands. Assume that we have an N x M digital image I with \( i, j \in \mathbb{Z}, 0 \leq i \leq N - 1, 0 \leq j \leq M - 1 \) and the current pixel position of the finger point is at \((i_1, j_1)\), while the previous position was at \((i_2, j_2)\). The chessboard distance is defined as:

\[
d_{\text{chess}} = \max\{ |i_1 - i_2|, |j_1 - j_2| \}
\]

(3)

Table.1 shows each of the directional commands. In the table, the variable \( \sigma \) can be change according to the frame rate of the camera properly. In our system \( \sigma=4 \) is used with the frame rate of 10fps, 24bit color, and a resolution of 320 x 240 pixels.

The instantaneous rate of change of the fingertip area is applied to the click command by finger gestures, and it is defined as the fingertip area of the current frame over the fingertip area of the previous frame. The click command occurs when a user moves his finger back and forth by clicking a mouse toward the camera.

3. Experiment Result and Application

3.1. Experiment and result

The proposed system is implemented on the Samsung Galaxy S smart phone, which is provided with a 1GHz processor, 512MB of memory, and a 5MP rear-facing camera. Accuracy assessments of fingertip detection and gesture recognition were performed under varying lighting conditions using both simple and complex backgrounds. We used the camera at a frame rate of 10 fps and a resolution of 120 x 160 pixels. We used a light meter to evaluate the performance of fingertip tracking under varying lighting conditions. Five lighting conditions were set as shown in Table 2, including average lux values.

<table>
<thead>
<tr>
<th>Place</th>
<th>Intensity of Illumination (Lux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition 1: Public areas with dark surroundings</td>
<td>20</td>
</tr>
<tr>
<td>Condition 2: Office</td>
<td>400</td>
</tr>
<tr>
<td>Condition 3: Corridor</td>
<td>1,000</td>
</tr>
<tr>
<td>Condition 4: Outdoor in shade</td>
<td>2,000</td>
</tr>
<tr>
<td>Condition 5: Out in sunshine</td>
<td>60,000</td>
</tr>
</tbody>
</table>
To evaluate the performance of the proposed fingertip detection, approximately 1,000 images including 100 images of each condition (five lighting conditions with simple backgrounds and five lighting conditions with complex backgrounds) were used in the real-time fingertip detection program. The trained cascade classifier for fingertip detection is a 13-stage cascade classifier with the required false alarm rate set at $1 \times 10^{-5}$, and its size is 20 x 10 pixels. For the detection results, we measured the number of hits, misses, false pictures, and the detection time and detection rate. (Table 2)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Hit</th>
<th>Missed</th>
<th>False</th>
<th>Detection Time (Sec)</th>
<th>Detection Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple background</td>
<td>Condition.1</td>
<td>98</td>
<td>2</td>
<td>1</td>
<td>0.097</td>
</tr>
<tr>
<td></td>
<td>Condition.2</td>
<td>100</td>
<td>0</td>
<td>1</td>
<td>0.112</td>
</tr>
<tr>
<td></td>
<td>Condition.3</td>
<td>99</td>
<td>1</td>
<td>0</td>
<td>0.104</td>
</tr>
<tr>
<td></td>
<td>Condition.4</td>
<td>98</td>
<td>2</td>
<td>1</td>
<td>0.099</td>
</tr>
<tr>
<td></td>
<td>Condition.5</td>
<td>100</td>
<td>0</td>
<td>2</td>
<td>0.101</td>
</tr>
<tr>
<td>Complex background</td>
<td>Condition.1</td>
<td>96</td>
<td>4</td>
<td>1</td>
<td>0.109</td>
</tr>
<tr>
<td></td>
<td>Condition.2</td>
<td>98</td>
<td>2</td>
<td>0</td>
<td>0.102</td>
</tr>
<tr>
<td></td>
<td>Condition.3</td>
<td>97</td>
<td>3</td>
<td>2</td>
<td>0.099</td>
</tr>
<tr>
<td></td>
<td>Condition.4</td>
<td>99</td>
<td>1</td>
<td>2</td>
<td>0.109</td>
</tr>
<tr>
<td></td>
<td>Condition.5</td>
<td>95</td>
<td>5</td>
<td>2</td>
<td>0.104</td>
</tr>
<tr>
<td>Average</td>
<td>98</td>
<td>2</td>
<td>1.2</td>
<td>0.103</td>
<td>97%</td>
</tr>
</tbody>
</table>

By analyzing the detection results, we found that the detection rate is 97%, and the detection time is 0.103 seconds. The proposed fingertip detection algorithm showed good robustness against lighting variance and complex background including skin-like color. As a result, even if skin color segmentation fails with complex backgrounds, our algorithm can successfully detect a fingertip using an MMGC image and the fingertip detection cascade. The resulting images of the fingertip detection procedure are shown in Fig. 3.

![Fig. 3: Detection result image: (a) Detection result with simple background, (b) Detection result image with complex background](image)

### 3.2. Application
We implemented a few test applications to demonstrate the proposed system’s strengths and limitations. One of the applications, a simple game called Arkanoid, is shown in Fig. 4. Users can move the small paddle easily and hit the ball using finger gestures. As a result, we demonstrated that our system can be applied to any other mobile application, such as a web browser, mobile game, or photo viewer, that is controlled by a mouse and keypad.

Fig. 4: Simple game application

4. Conclusion

This paper proposes the robust fingertip detection method using the Adaboost algorithm under dynamic lighting conditions and against complicated backgrounds for a finger-gesture-based mobile user interface system. A user interacts with a mobile application by using finger gestures with the point change, which is detected by the Adaboost algorithm. As a result, the proposed fingertip detection method is very effective under varying lighting conditions and against complex backgrounds, and mobile applications can be controlled by the proposed finger gesture-based mobile user interface system.

5. Acknowledgements

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6. References